RECOMMENDED STRATEGY OF HYDROGEN INTEGRATION TO DECARBONIZE JAPAN'S ENERGY MARKET

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ABSTRACT OF

BACHELOR'S THESIS

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Objectives: The main objectives of this theses were to investigate Japan's current strategies for the integration of hydrogen in their energy market and contrast it against relevant literature and perspectives to recommend a more effective plan that would help Japan achieve their goals for sustainable energy generation.

Summary: The viability of Japan's current hydrogen strategy is questioned over its effectiveness to appropriately address the energy and environmental concerns they face. To understand the strategy and investigate ways to improve it, analyses of Japan's ongoing hydrogen projects and an interview with a hydrogen strategy consultant were conducted to gather varying perspectives on Japan's progression on the integration of hydrogen energy.

Conclusions: Japan's strategy for hydrogen integration was found to be misguided in several aspects, focusing too much on cost reductions and the public use of hydrogen. By shifting their priorities toward long-term environmental benefits over short-term cost-competitiveness, it was established that Japan could support projects that realize an effective and sustainable energy market.

Key words: Energy market, hydrogen energy, Japan, supply chain, FCV, energy certificate

Language: English

Grade:

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1 - INTRODUCTION

1.1 – Background

As the considerations of a worldwide energy shortage and of environmental protection continue to rise in importance among the world's economies, a comprehensive strategy must be formulated to effectively address these issues. As a result, nations have turned to the exploration of sustainable energy generation (Zhao, 2022). This direction can produce a multitude of benefits across the economic, environmental, and social dimensions (United Nations, n.d.). However, governments and businesses must cooperate to accomplish these outcomes. The struggle to initiate such a change is clearly visible within the energy market of Japan.

The development of the Japanese energy market has been tumultuous over the years. Like other global superpowers, Japan aims to establish a renewable energy-based system as seen through their signing of the Kyoto Protocol in 1997 and of the Paris Agreement in 2015: legally binding international treaties that call for action against climate change (Ministry of Foreign Affairs of Japan, 2022). Still reeling from the implications of the nuclear meltdown in Tohoku in 2011, Japan has exhibited an enduring reliance on liquefied natural gas (LNG) and coal that has raised questions over the nation's progress towards achieving their goals for sustainable energy (Tachev, 2022). Various plans and strategies have been formulated by the Japanese government to mitigate these concerns. Of all the possibilities discussed, a return to nuclear energy and the expansion of the domestic renewable energy sector appears to be the most plausible opportunities (Wu, 2020). However, both options present their own challenges and problems that may disrupt Japan's efforts to attain sustainable energy. Nuclear energy faces stiff public opposition and lagging recovery due to slow and expensive safety checks of nuclear plants (Arnold-Parra, 2022). Expanding the renewable energy sector is restricted by financial and geographical obstacles of constructing renewable energy sites such as solar and wind farms as well as their intermittent energy generation (Tachev, 2021). Amidst the uncertain future of the Japanese energy market, a relatively new opportunity is beginning to attract attention as the solution to Japan's energy dilemma: the integration of hydrogen energy. Although research into the logistics of its implementation is limited, its benefits and implications are promising and have piqued the interest of nations around the world (IEA, 2019).

This thesis will investigate the possibility for integrating hydrogen energy in the Japanese energy market. A literature review will be conducted to establish a basic understanding of the Japanese energy market and analyze current research that explores the potential presence of hydrogen energy in it. Additionally, a conceptual framework will be formulated to serve as the basis for the research performed throughout this thesis. The research will be primarily derived from secondary sources with a semi-structured interview organized to provide further insight. The findings are then analyzed against the contents of the literature review to facilitate a meaningful discussion of the topic. In the latter sections of the thesis, policies to support the integration of hydrogen energy and their implications for the local government, businesses, consumers, as well as foreign entities will be investigated. Finally, the thesis will conclude by exploring connections to the realm of international business and identifying opportunities for further research that would nurture a deeper understanding of hydrogen energy.

1.2 – Research Problem

Despite the limited research available on the widespread use of hydrogen energy, its contributions to attaining sustainable energy generation have been reinforced by empirical studies of its performance as an energy carrier (Møller, 2017). It is essential to scale this knowledge up to an appropriate level for its applicability on a nation-wide level. The pressure of external factors such as the rising price of energy imports such as coal and LNG (Nagle, 2022) as well as the looming deadline of 2050 for net-zero emissions set in the Paris Agreement (United Nations, n.d.) heightens the importance of transitioning towards hydrogen energy. This highlights the need to acknowledge its superiorities over other solutions for sustainable energy generation in the Japanese energy market and realize a comprehensive strategy for its implementation.

1.3 – Research Questions

The purpose of this thesis and the research conducted, is to answer the following questions:

1. How has the Japanese energy market changed since the 2011 nuclear meltdown?
2. How will hydrogen energy allow Japan to achieve sustainable energy generation?
3. How can Japan reconfigure their strategy for hydrogen integration to effectively achieve an economically viable and environmentally considerate energy market?

1.4 – Research Objectives

The objective of this research is to investigate the functions and benefits of hydrogen energy for achieving sustainable energy generation and how it can be effectively integrated in the Japanese energy market through processes of literature and empirical qualitative research. In addition, its implications on various stakeholders as well as on the realm of international business will be explored.

1.5 – Definitions

An energy market can be summarized as “a commodity market that deals specifically with the trade and supply of energy” (WatchWire, n.d.). Currently, there is no literary consensus on a shared definition for an energy market, but the term is often adapted from the definition of a market procured from economics. A market can be defined as “a place where parties can gather to facilitate the exchange of goods and services” (Kenton, 2021). While both operate closely on the concept of exchange, an energy market differs in its high degree of complexity due to its sheer size and the number of participants constantly involved.

Sustainable energy generation is described as the "provision of adequate, reliable, and affordable energy, in conformity with social and environmental requirements" (Grigoroudis, 2019). While some definitions may focus on the environmental considerations of energy generation, the term also considers its economic and social viability in the context of meeting the energy needs of the current generation without compromising those of future ones.

2 – LITERATURE REVIEW

2.1 – Introduction

This literature review aims to create a solid platform from which a conceptual framework can be developed to be able to observe the interactions and relationships between the variables explored throughout this thesis. This review critically analyzes research that has already been performed on the structure of the Japanese energy market and its accommodations of hydrogen energy. Moreover, the implications of the presence of hydrogen in Japan's energy grid in terms of economic, environmental, and social impact will be touched upon before being explored in depth in later sections of the thesis. This exploration will assist in answering the research questions posed earlier in the thesis.

As a research topic, the Japanese energy sector is plentiful due to the fluctuations it experienced following the nuclear meltdown in Tohoku in 2011. Therefore, many discussions exist regarding the reintegration of nuclear energy into Japan's energy market as well as potential expansions of efforts in renewable energy sources such as photovoltaic and wind energy. Moreover, the concept of a hydrogen-driven energy market in Japan is relatively new and lacks concrete documentation concerning its implementation. Despite this, Japan is globally renowned as a "leader in [hydrogen] fuel cell technology" (Nakano, 2021), ensuring that there is enough existing research to facilitate a literature review for this thesis.

When choosing which pieces of literature to review, a set of criteria will be used to gauge the validity and relevance of the source in the thesis. An important criterion is the legitimacy of the source. While this element can be subjective at times, this literature review only considers sources originating from government and corporate bodies as well as scholarly journals to be legitimate. Another criterion is the date of publication. The idea of accommodating hydrogen into the Japanese energy economy has fluctuated drastically in recent years, so sources that discuss this topic earlier than the publication of Japan's Basic Hydrogen Plan by the Ministerial Council on Renewable Energy, Hydrogen and Related Issues (2017) are not considered. However, sources that are used to define concepts are exempt from this criterion. Other criteria include the methodology and sources of the research, and the consideration of any existing critique from other studies that may contradict a source's content.

This literature review will first define critical concepts pertaining to energy markets and then overview the Japanese energy market. This will provide adequate background information to understand the basics of the Japanese energy market. Then, the recent history of the Japanese energy market will be investigated, effectively answering the first research question, "How has the Japanese energy market changed since the 2011 nuclear meltdown?", allowing for an understanding of the market's current circumstances. Afterwards, the accommodation of hydrogen energy in the Japanese energy market will be extensively explored, providing a base from which to address the second research question, "How will hydrogen energy allow Japan to achieve sustainable energy generation?". Towards the end of the literature review, Japan's current strategy for hydrogen integration will be briefly investigated as well public opinions on the plan. The review will conclude with a conceptual framework to visualize the effective integration of hydrogen energy into the Japanese energy market.

2.2 – Energy Markets

To establish a clear understanding of the scope of this literature review, it is necessary to observe and analyze the Japanese energy market. To do so, the critical concepts relating to energy markets in general will be defined. Following this, the Japanese energy market will be explored, providing a contextualized perspective with which the topic of the thesis can be properly addressed.

2.2.1 – An Overview of Energy Markets

Around the world, there typically exists two types of energy markets: a regulated or an unregulated energy market. WatchWire (2022) explains that a regulated energy market “contains utilities that own and operate all electricity” while a deregulated energy market “allows for the entrance of competitors to buy and sell electricity by permitting market participants to invest in power plants and transmission lines”. In short, the primary difference lies in the control of the supply of energy, where regulated markets have one entity in charge of energy generation, transmission, and distribution, while deregulated markets divide the responsibilities among private entities. In 2016, the Japanese government amended the national Electricity Business Act: a mandate to liberalize the collective energy market for consumers, allowing them to seek their own energy supplier outside of the monopoly of electricity retailers (Kobayashi, 2020). Therefore, the Japanese energy market will be considered a deregulated market, which will be the variant referred to when using the term, ‘energy market’. For additional context, a simplified representation of an energy market and its participants can be observed:

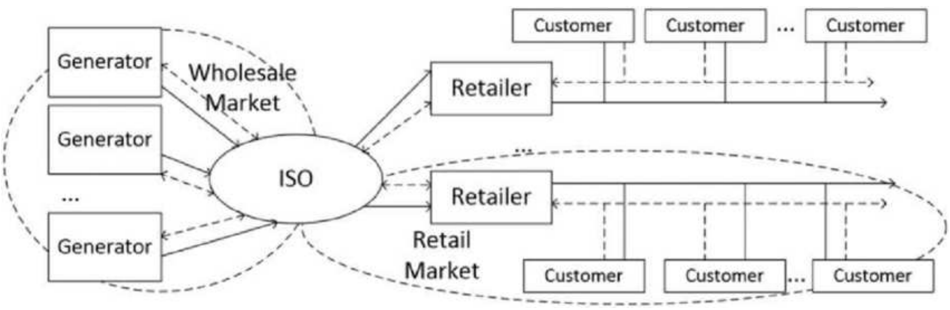


Fig. 1: Visualization of an energy market (Liu, 2018)

Fig. 1 shows an energy market being composed of two subsidiary markets, those being the wholesale market and the retail market. The wholesale market describes the interactions between the energy generators and the retailers, using a transmission network to carry electricity long distances at high voltages to transmission systems. The retail market describes the interactions between the retailers and the consumers, using a distribution network to carry electricity short distances at low voltages to consumers (EnergyUK, 2022). The independent service operator (seen as ‘ISO’ in Fig. 1) functions as the coordinator between the two markets. The ISO’s primary roles include determining the marginal clearing price (also known as the equilibrium price of electricity) and scheduling power generation to meet the demand of the retailer market (Liu, 2018). The ISO operates as an overarching authority and does not directly participate in the energy market. As such, the direct participants of an energy market are the energy generators, the energy retailers, and the consumers. Each participant plays a role in the integration of new policies which will be explored in depth later.

2.2.2 – Regional Division of the Japanese Energy Market

Unlike other energy markets such as those of the US and China, Japan is an island country with no cross-border interconnections which facilitate a flow of energy from overseas, meaning the country must handle its own energy production and consumption. Consequentially, Japan focuses its efforts on power generation and transmission and wholly relies on imports for primary fuel sources. A unique aspect of the Japanese energy market is that it is comprised of ten individual sub-markets which are tied to specific regions of the country. Every market has its own ISO to coordinate its activities. The division of the Japanese energy grid is further emphasized by the discrepancy in electricity frequency used. Due to historical reasons relating to the city of Tokyo first purchasing generators from AEG in Germany (50Hz) and the city of Osaka purchasing them from General Motors in the US (60Hz), the Eastern and Western halves of the nation popularized different electrical frequencies (IEA, 2022). This decision has led to many complications concerning the interconnectivity of energy between regions of Japan which will be explored in a later section. A visual representation of the division of Japan's energy grid can be observed:

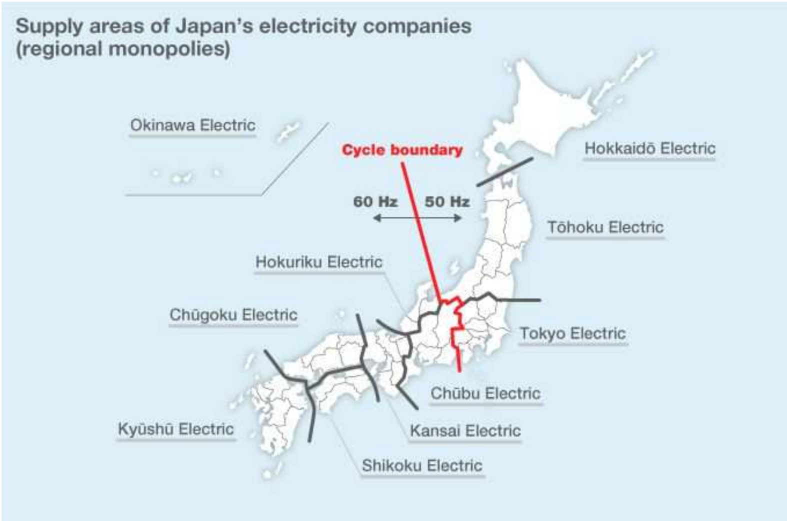


Fig. 2: Division of Japanese energy grid (Motoshige, 2012)

2.2.3 – Deregulation of the Japanese Energy Market

Although it has been established thus far that Japan's energy market is deregulated, it must be emphasized that it has only been so for a short time. The regional energy markets of Japan (seen in Fig. 2 separated by the gray lines) were once monopolized by their local municipal electricity. The presence of energy monopolies perpetuated barriers between these regions and therefore can be attributed as the main reason behind the lack of interconnectivity between Japan's regional energy markets (Kennedy, 2022).

This framework began to change when Japan called for the deregulation of these energy markets in 1995. The impetus for this decision aligned with the global trend of energy market deregulation of the 1990s and in Japan's case, it aimed to correct the nation's high-cost structures and its generally high prices relative to other nations. This process experienced several significant reformations. In 1995, independent power producers and private electric utilities were granted access to the energy market. A revised electricity rate system as well as a fuel cost adjustment system were also nationally implemented. In 1999, 'extra-high-voltage' customers (that require >20,000V for energy transmission) were granted market liberalization, thus allowing independent power producers and private electric utilities to supply electricity directly to those eligible customers under fair and equitable conditions. These customers included factories, office buildings, and department stores. The represented the opening of the Japanese energy retail market. In 2003, 'high-voltage' customers (that require >500V for energy transmission) were granted the same privileges. These customers included supermarkets and medium-sized buildings. In 2008, the wholesale energy market was fully liberalized, allowing free entry into the power generation sector. Finally, in 2016, 'low-voltage' customers (that require <500V for energy transmission) were also offered the same opportunities, thus completely liberalizing the Japanese energy retail market. These customers included convenience stores, small offices, and private households. Although both subsidiary markets are now liberalized, new entrants must be registered according to a determined process to be eligible (TEPCO, 2016). However, it must be noted that despite the trend of deregulation, the transmission and distribution sector continued to be operated by government-licensed companies to ensure a stable energy supply. This format operates as a fail-safe system for energy retailers; if they cannot purchase the amount of power required to satisfy a customer's contract, the regional ISO will compensate for the difference to ensure that electricity is delivered to the consumers, though this format would later change (Agency for Natural Resources, n.d.).

2.2.4 – The Japanese Wholesale and Retail Energy Markets

As mentioned prior, an energy market is comprised of the wholesale market and retail market that manages the interactions between generators and retailers, and retailers and customers respectively. The Japanese wholesale energy market is primarily coordinated by the Japanese Electric Power Exchange (JEPX). The JEPX was founded in 2003 and began operations in 2005 with the purpose of serving as an intermediary corporation to facilitate electricity sales between energy generators and retailers. The JEPX is a private corporation, meaning it is not government-licensed, but it acts as Japan's only wholesale electricity exchanger with virtually no competition. However, it must be noted that generators and retailers can trade freely outside of the JEPX on their own terms and negotiations. The appeal of participating in the JEPX comes from their blind single-price auction mechanism that enhances competition among market participants and improves the efficiency of contract formations and general energy trade. The JEPX allows for bidding in three types of markets: 1) the spot day-ahead market; where units of electricity are ordered for the next day, 2) the hour-ahead market; where units of electricity are immediately ordered to compensate for deficient deliveries from the spot day-ahead market, 3) the forward market; where units of electricity are pre-ordered for the future through negotiations of current-day prices (Dupuis, 2021). Additionally, since 2018, the JEPX has operated a green certificates market where energy producers can sell “non-fossil fuel energy certificates” which serve as evidence that their energy was produced in a sustainable manner (CMS, 2021). The rules of trading in the JEPX are approved by the Japanese Ministry of Economy, Trade, and Industry (METI) (Kobayashi, 2020).

Unlike the wholesale market, the Japanese energy retail market does not have a primary platform through which contracts are formed. In its liberalized state, customers visit the websites of various retailers to compare their energy plan’s rates and services. Then, customers submit an online application form to establish a new contract or to change providers (most often in the case that consumers wish to change from one of the former monopolies), making market interactions completely individual (Agency for Natural Resources, n.d.). Since the dissolution of the retail market monopolies, new companies have been able to freely enter and compete for market share. There are currently 730 firms that are registered as participants in the retailer market (Agency for Natural Resources, n.d.). Despite the inflow of competition and the opportunity for consumers to switch suppliers, the former monopolies (known as incumbent utilities) still retain 74% of market share across the national energy market while new retailers take up 18% (Klein, 2023). The relative lack of switching of energy retailers is attributed to many factors, such as the perceived expertise of incumbent utilities, the lack of information disseminated by new retailers that force consumers to invest more time and effort in searching for alternative retailers (Nogata, 2022), and the use of bundling strategies (grouping of utility plans, often for convenience and savings) to increase switching costs

(Murakami, 2022). As a result, incumbent utilities continue to control a large majority of the energy retail market.

2.2.5 – How the Japanese Energy Market Has Changed since 2011

The earthquake and tsunami that hit Japan in 2011 serves as a turning point in national history for many reasons, with Japan's energy market being one of the most impacted sectors. An immediate change carried out after the disaster was the complete deactivation of all nuclear power generation in the country. Up until the disaster, nuclear power contributed 32% of Japan's energy mix. While deemed the politically correct decision due to the consequences of the meltdown, the financial conditions of energy retailers crumbled as fuel costs increased to compensate for the lack of nuclear power. The increase in fuel costs for all incumbent utilities (excluding Okinawa due to the region not having any ties to nuclear plants) between 2011-2012 is estimated to be 3.2 trillion JPY. This change was so drastic that it sent ripple effects across the entire Japanese economy, deteriorating their trade balance, making Japan record a trade deficit for the first time in 31 years. To compensate for the elimination of nuclear power from the national energy mix, Japan's consumption of LNG increased which greatly supported the energy sector but proved to only a short-term solution (Goto, 2016). However, their energy production has not yet returned to the volume produced prior to the disaster (IEA, 2022). The consequences of nuclear power witnessed during the disaster led to an overhaul of the system of administration of nuclear power to optimize its regulation and maintenance work. This resulted in the formation of the Nuclear Regulation Authority (NRA) in 2012 as an affiliated agency of the Ministry of Environment that would license nuclear power plants. This license is predicated on a safety review by the NRA along with granted consent provided by the regional government's consent. Additional organizations were formed to heighten the safety of reactivating nuclear power plants such as the Japan Nuclear Safety Institute (JANSI) and the Atomic Energy Association (ATENA) in 2012 and 2018 respectively. JANSI encouraged nuclear plants to voluntarily strive for operational safety and raise safety standards while ATENA drafts effective safety measures for nuclear plant operators to follow (JEPIC, 2022). As a result, nuclear energy has experienced a gradual rise in usage following its dramatic drop in 2011. The changes in Japan's energy mix after 2011 are visually represented:

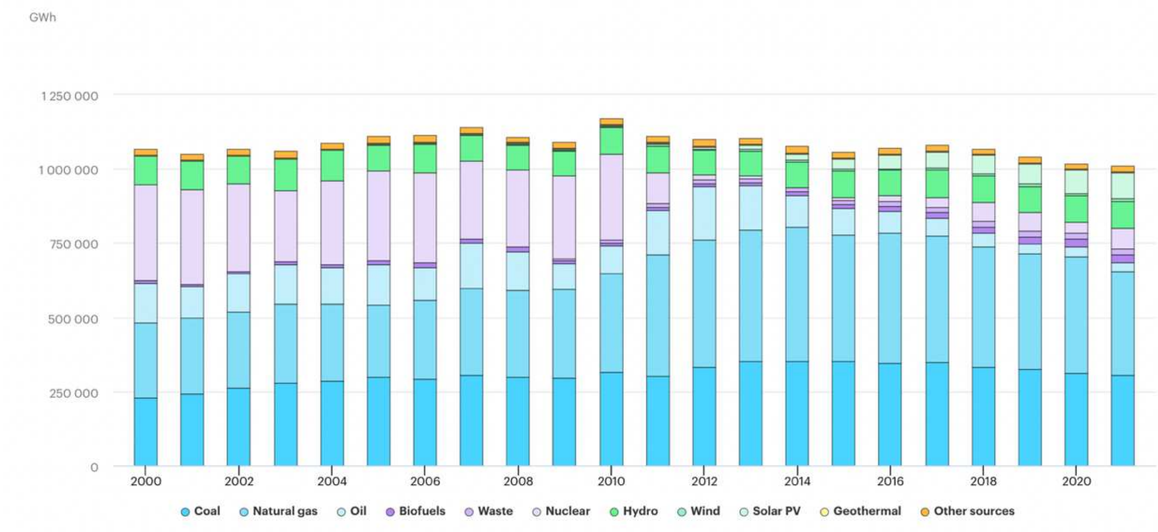


Fig. 3: Electricity generation by source in Japan, 2000-2021 (IEA, 2022)

The restructuring of Japan's energy mix elevated the significance of renewable energy. Initial projects that assisted with the adoption of renewable energy included the introduction of a system in place for purchasing excess solar energy from producers in 2009 and a feed-in tariff (FIT) scheme in 2012. The Japanese FIT is defined as the 'purchase [of the total output of] renewable-generated electricity [by electric utilities and merchants] at prices and contract durations set by the Ministry of Economy, Trade, and Industry. End users then pay a surcharge to help cover the renewable portion of the total power supply' (Ichigo, n.d.). This would ensure continuous investment in the renewable energy sector through guarantees in purchases since retailers would be reimbursed with customer surcharges to make up the difference between the price of renewable energy and the market price of electricity. Each year, METI revises the tariff cost to reflect changes in competition and technological innovation. This system rapidly advanced capital investments in renewable energy, expanding the sector by 60GW from 2012-2020. However, due to rising surcharge prices, METI overhauled the system in 2020 to adopt a feed-in premium (FIP). Instead of having retailers purchase the total output of renewable energy producers at a set price irrespective of market value, FIP allows retailers to buy their desired amount of energy at a premium. That premium is then repaid to retailers through customer surcharges. This system directly links revenue and market price which provides the market with a level of price consistency. Moreover, FIP incentivizes generators to produce more energy during peak hours of consumption since their revenue is linked market price and therefore demand (JEPIC, 2022). The platform of the FIT and FIP scheme has incentivized the consumption of renewable energy throughout the nation, particularly solar energy, as seen in its increased use after 2011 in Fig 2. While the FIP system operates to encourage the sale of purely renewable energy, it covers energy sources such as solar, wind, geothermal, hydro, and biomass power, while hydrogen energy is not included on the list. To accommodate for the recent entry of hydrogen in the Japanese energy market, the JEPX reconfigured their green energy certificates market in 2021 by splitting it into two sub-markets: (1) a certificate market under the Act of Sophisticated Methods of Energy Supply Structure, and (2) a Renewable Energy Value Trading Market. (1) serves as a market for non-fossil fuel energy certificates that aren't included in the FIP scheme while (2) sells certificates for non-fossil fuel energy which are included. In the case of hydrogen, its certificates would be traded in (1) since it is not approved as an FIP energy source (CMS, 2021).

The disaster also served as the impetus for another reformation of energy market as the Japanese government approved a new policy called the Electricity System Reform in 2013. The policy was divided into three phases that would be implemented throughout the seven years: 1) the establishment of a central ISO to monitor and manage each subsidiary region of Japan, 2) the complete liberalization of the energy retail market, 3) the legal unbundling of the transmission and distribution sector.

The fundamental element of this policy about responding to the nuclear meltdown was the central ISO. The disaster exposed a crucial flaw in the division of the national energy grid. The difference in frequency between the Eastern (50Hz) and Western (60Hz) halves of Japan prevents energy transmission across the cycle boundary (seen as the red line in Fig. 2). While there are a few frequency converter stations situated at the boundary to address this issue, their capacity was not enough to mitigate the rolling black outs that followed the disaster (Hiroshi, 2014). This concern fueled the necessity to form an organization that would promote and coordinate cross-regional electricity transmission. This organization would eventually be created in 2015 as the Organization for Cross-regional Coordination of Transmission Operators (OCCTO). A primary function of the OCCTO is to balance energy supply and demand across service areas to address energy deficits and optimize the existing power capacity in Japan. A project borne from this function was the expansion of frequency converters in Japan. This led to the Shin-Shinano frequency converter located in the city of Nagano receiving from 2017-2021 that amplified its interconnective capacity from 1,200MW to 2,100MW (Toshiba, 2021). The objective of liberalizing the energy retail market also falls in line with the pursuit of cross-regional energy transmission, since allowing households to contract retailers outside of their geographic area requires a high degree of energy grid interconnectivity. Additionally, the legal unbundling of the transmission and network sector will result in separate business entities to promote equal access to the energy market for new entrants. However, licensing is required for companies to be eligible to enter this sector. This decision was made with the rise of renewable energy companies in mind. This also helps the sector realize a competitive market environment like what is occurring in the wholesale and retail energy markets (Goto, 2016). The achievement of cross-regional energy transmission eventually led to a wheeling system that was integrated throughout the energy market in 2015 (JEPIC, 2022). Wheeling is defined as 'the delivery of energy from a generator to an end-user located in another area using an existing distribution or transmission networks' (Eskom, n.d.). Wheeling allows the cross-regional energy grid to be utilized for more than emergency energy transmission services in the case of a disaster, but now consumers can search for energy retailers outside of their own geographic area. In 2020, a wheeling rate system for cross-regional transmission was implemented by the OCCTO to encourage the transmission and distribution sector to pursue cost efficiencies (JEPIC, 2022). However, renewable energy groups believe that this addition will be detrimental to the growth of their sector. Naoaki Eguchi, co-head of the renewable group at Baker McKenzie's Tokyo Office, states that non-renewable energy retailers can pass the cost down to their customers as a surcharge while renewable projects will not share the same ability due to the fixed tariff rate of the FIT scheme (Fernandez, 2019).

A regional Japanese energy market can now be visualized with consideration of its unique features such as wheeling and its FIT scheme:

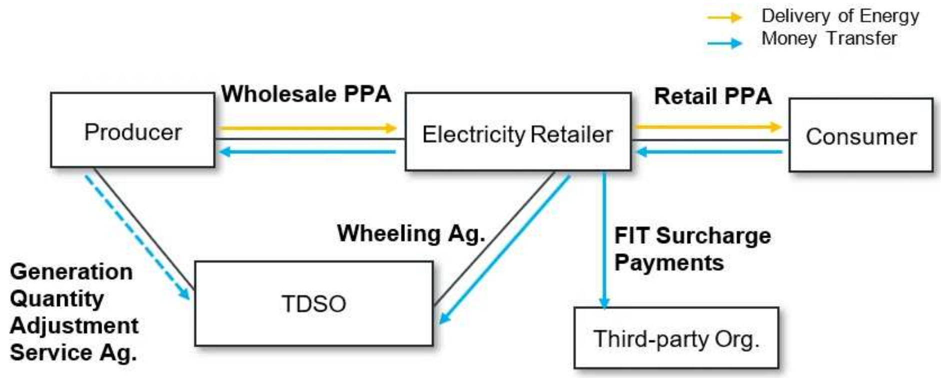


Fig. 4: Regional Japanese energy market (Wakabayashi, 2021)

2.2.6 – Japan's Current Energy Production Mix

Japan's energy production mix has changed drastically over the years, with the events of 2011 serving as a catalyst for the nation to reevaluate their energy sector. A breakdown of Japan's energy production sources in 2022 can be observed:

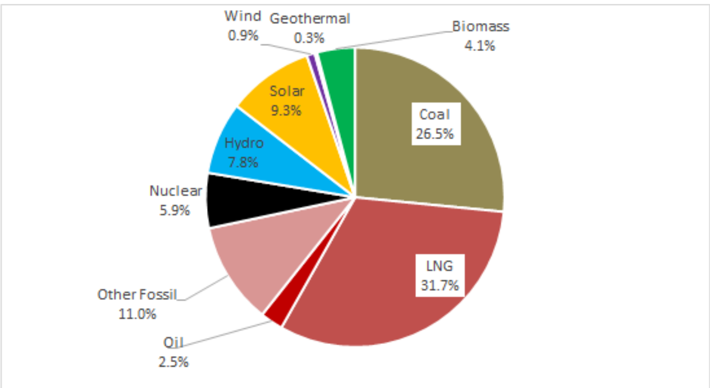


Fig. 5: Breakdown of Japanese energy mix, 2022 (ISEP, 2022)

As observed in the trends explored in section 2.2.5 and mirrored in Fig. 5, Japan's phase-out of nuclear energy in 2011 led to a significant increase in the reliance on LNG, but fostered an increase in production of renewable energy, particularly solar and hydro power. And despite the phase-out, nuclear energy regained a sizable share in the energy mix following rigorous safety reviews conducted by the NRA.

2.2.7 – Japanese Government Energy Policy Objectives

Japan's long-term strategic energy plan was unveiled in 2020 as the 'Green Growth Strategy Through Achieving Carbon Neutrality in 2050'. The strategy centers itself around the development of fourteen growth industries and implementing a comprehensive action plan for each. The growth industries are observed:

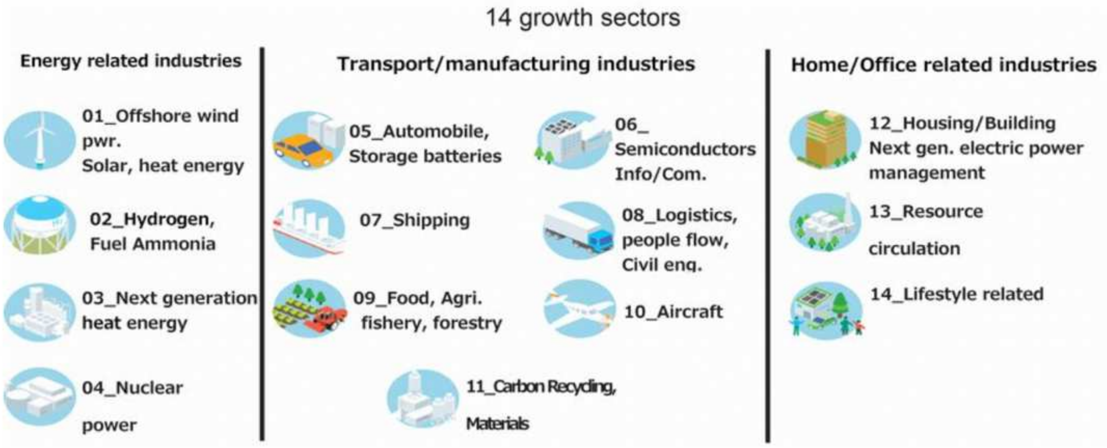


Fig. 6: Growth sectors of Japan's green growth strategy (METI, 2022)

The green growth strategy aims to continue reconstruction efforts of the 2011 disaster on top of responding to climate change and concerns of the energy supply and demand structure. The strategy is founded on the concept of '3E+S' that strives for energy security, economic efficiency, and environmental protection without compromising safety. It possesses two phases with goals set at 2030 and 2050. For its short-term objectives, Japan sets goals for each of the dimensions of 3E+S: 1) for energy security, achieve an energy self-sufficiency rate of 30%, 2) for economic efficiency, reduce energy generation costs in anticipation of rising surcharges, 3) for environmental consideration, reduce CO2 emissions by 45%, 4) for safety, enhance the safety of nuclear energy (JEPIC, 2022). Japan's green growth strategy is projected to change their energy production mix by the amounts observed:

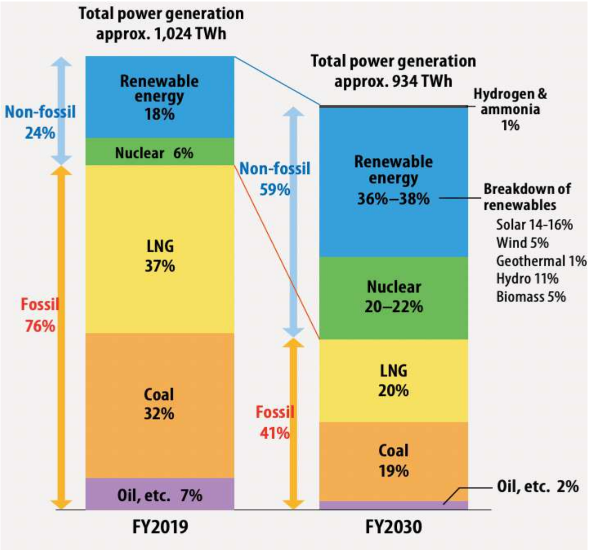


Fig. 7: Energy generation mix through Japan's green growth strategy by 2030 (JEPIC, 2022)

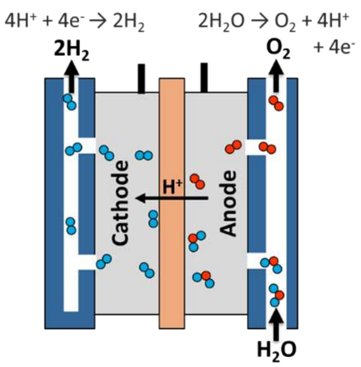
As seen in Fig. 7, a large emphasis is placed on the continued development of renewable energy sources and nuclear energy while suppressing the use of LNG and coal. At the same time, Japan will look beyond the current options available to pursue innovative options to increase the share of non-polluting sources in the energy mix.

2.3 – Hydrogen Energy

Hydrogen is an element with great potential as a fuel source for societies around the world. Although research into its viability may be scarce around the world, Japan is renowned as a leader in this department. When classifying energy sources, there are two general types: primary and secondary sources. Webber and Glazer at the University of Texas define primary energy sources as 'unconverted or original fuels' which includes fuels such as petroleum, biomass, and solar radiation that can be harnessed directly. They define secondary energy sources as 'resources that have been converted or stored' which includes fuels such as electricity, heat, and biofuel that originates from the conversion of a primary source (Webber, n.d.). They are also known as energy carriers. From these definitions, hydrogen is categorized as a secondary energy source since it cannot be harnessed directly.

2.3.1 – Utilizing Hydrogen as an Energy Carrier

Hydrogen is formatted as an energy carrier primarily through the formation of an electrolyzer or a membrane reactor. The US Department of Energy states that an electrolyzer uses a process called electrolysis to split water molecules into hydrogen and oxygen atoms using electricity while a membrane reactor uses steam-methane reforming to cause the two components to react and create hydrogen with small amounts of CO2 (Office of Energy Efficiency, n.d.). These methods create a wide range of hydrogen that exists on a color spectrum. The primary types that will be addressed in this thesis are gray, blue, and green hydrogen. Gray and blue hydrogen are both formed using fossil fuels, but blue hydrogen restricts the CO2 that is produced through a process known as carbon capture and storage (CCS). Green hydrogen is typically produced using the electrolysis of renewable energy and therefore creates no pollutants (National Grid, n.d.). The hydrogen that is produced by either method is then stored in a tank next to a hydrogen fuel cell. According to the National Energy Education Project, a hydrogen fuel cell is an electrochemical cell unit with opposing ends filled with stored hydrogen and oxygen from the air. The interaction of these atoms in the central chamber produces electricity with water and small amounts of heat (U.S. Energy Information Administration, n.d.). The two processes are inverses of each other. Together, energy that is generated is first electrolyzed/reformed and stored as hydrogen in fuel cells. Then, when fed oxygen, fuel cells can convert the stored hydrogen back into electricity. All the described processes are observed:



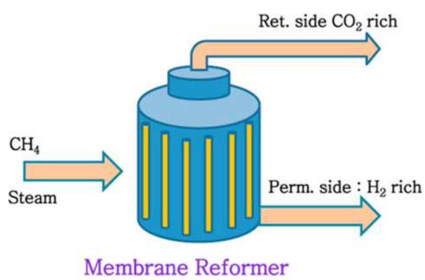


Fig. 8: Electrolysis (Office of Energy Efficiency, n.d.), Fig. 9: Steam-methane reforming (Kim, 2018)

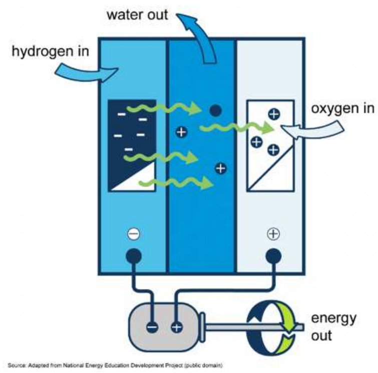


Fig. 10: Hydrogen fuel cell composition (U.S. Energy Information Administration)

2.3.2 – Advantages of Hydrogen in an Energy Market

The Fuel Cell & Hydrogen Energy Association provides a list of the valuable features that hydrogen possesses as an energy carrier. Firstly, it can store energy for later use. This is a useful feature that addresses the intermittence of renewable energy generation since the conditions for stable energy production are circumstantial (FCHEA, n.d.). This also allows the transportation industry to tap into renewable energy since it can be stored in mobile fuel cells, a significant benefit for long-distance carriers such as planes and cargo ships which are difficult to decarbonize (IEA, 2019). Hydrogen energy produced through electrolysis is non-polluting since its only by-products are water and heat, complementing the use of renewable energy and its objective to cut carbon emissions. Even with steam-methane reforming, carbon emissions can be absorbed through CCS techniques. Hydrogen energy is also much more efficient than combustion or steam engines due to the chemical nature of its energy conversion. The US Department of Energy Hydrogen Program claims that a standard combustion engine operates at 20% efficiency while hydrogen fuel cells can achieve rates of 40-60% (Viessmann, 2022). The high density of hydrogen also makes fuel cells favorable over batteries since they weigh comparatively less and can store more fuel (Umicore, 2022). Its energy generation can also be scaled up exponentially since fuel cells can be stacked, allowing it to be used in a wide variety of applications from small, remote heating units to city-wide energy grids (FCHEA, 2022). Beyond economic and environmental benefits, hydrogen energy introduces an entire sector of employment, skills and responsibilities that have not yet been introduced to society. Positions ranging from fuel cell technicians to hydrogen plant operators that require a strong and technical skill set will help expand the hydrogen energy sector (Bezdek, 2019).

2.3.3 – Creating a Hydrogen Economy

Hydrogen energy has many versatile capabilities that allow it to be implemented across various stages of an energy market.

For energy generation, steam-methane reforming can be used to decarbonize non-renewable sources such as fossil fuels while electrolysis can store the energy of renewable sources to make its use more flexible. The incorporation of hydrogen in the energy generation sector requires a stable hydrogen supply chain to be developed. This includes a system for the conversion of electricity into hydrogen and its storage. For the former, a comprehensive series of electrolyzers, membrane reactors or other chambers to facilitate pyrolysis or partial oxidation (secondary processes that form hydrogen) need to be constructed to establish a large productive capacity for hydrogen. For the latter, hydrogen requires specialized liquid hydrogen (LH2) chambers that operate at 20K (-253°C) to store it as a liquid (which is more efficient that storing hydrogen as a gas due to liquid's greater density). However, the technology to produce such chambers are already advanced with the first mobile LH2 storage unit successfully transported 75 tons of LH2 from Australia to Japan in 2019 (Ratnakar, 2021). The primary objective for this sector will be to achieve competitive levels of hydrogen pricing through cost reductions in hydrogen generation and storage.

For energy consumption, hydrogen energy can be repurposed for a variety of functions, such as hydrogen refuelling for cars or residential fuel cells/heating for common household use, fuel cell plants for energy grids and general industrial demand, and hydrogen fuel cells for long-distance transportation (Kim, 2023). The two main areas of concern are hydrogen transmission and hydrogen refuelling. Transmission can be handled in two ways: through vehicular delivery (liquid) or pipeline transmission (compressed gas). The selection of these methods is dependent on the hydrogen demand and the distance required to transport the hydrogen with lower levels favoring vehicular transport and higher levels favoring pipelines. These methods will allow hydrogen to be transported to households and industrial grids for energy generation. For hydrogen refuelling, stations need to be established widespread across a region for fuel cell vehicles (FCVs) to recharge. For efficiency purposes, it is recommended to set up refuelling stations that perform on-site electrolysis using grid power and periodic deliveries of hydrogen through the previously mentioned transmission techniques to provide reliable and consistent hydrogen recharging to the public (Li, 2019).

A sustainable hydrogen economy in consideration of a supply chain that manages energy generation, storage, and transmission can be observed:

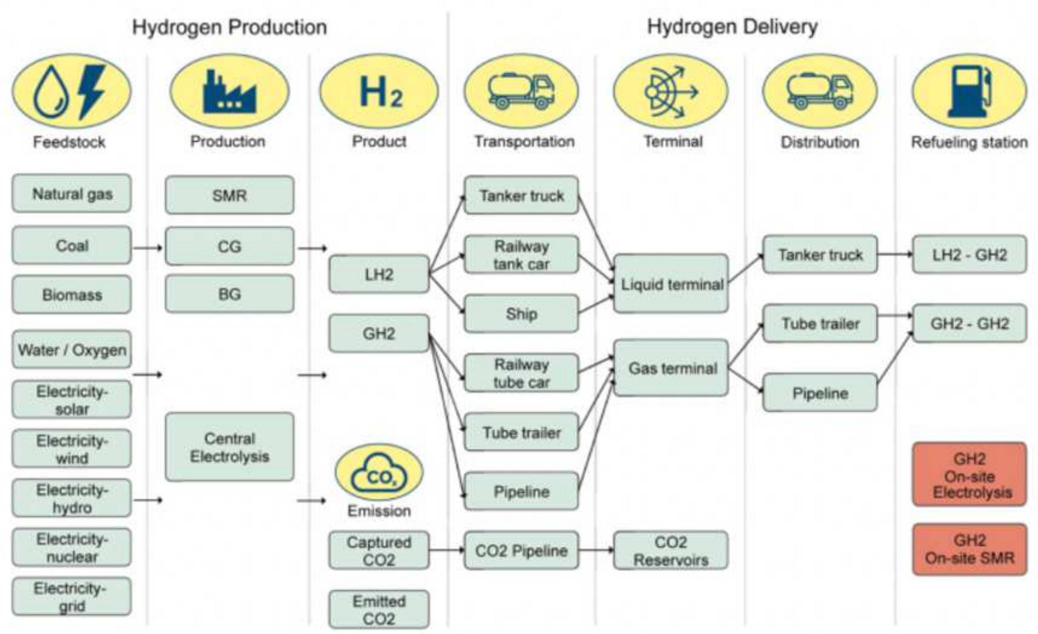


Fig. 11: Hydrogen supply chain (Li, 2019)

2.4 – Incorporating Hydrogen into the Japanese Energy Market

The implementation of hydrogen across the Japanese energy market requires more specification than the opportunities explored in 2.3.3. To gauge its viability, Japan's own hydrogen strategy will be analyzed.

2.4.1 – Japan's Basic Hydrogen Strategy

Japan released a document titled 'Japan's Basic Hydrogen Strategy' in 2017 to lay out their plans of incorporating hydrogen in the energy market to simultaneously achieve energy security and reduce greenhouse emissions. The strategy is divided into three phases to be accomplished by 2050: 1) between 2017 and the late 2020s, Japan aims to dramatically expand the use of hydrogen in the nation through fixed fuel cells and FCVs 2) between the 2020s and 2030s, Japan aims to establish a large-scale hydrogen generation and supply system, 3) by 2050, the hydrogen supply system should be pollutant-free through either the use of CCS or renewable energy electrolysis (Ministerial Council, 2017). In terms of reducing greenhouse emissions, Japan plans to cut emissions by 26% from 2013 levels by 2030, cutting out 310 million tons of CO2 through domestic absorption/reduction with an extended plan to eliminate 80% by 2050 (Ministerial Council, 2017).

Japan's focus on hydrogen allows them to reevaluate their energy supply system, which now relies heavily on randomly located fossil fuel sources overseas. Japan plans to diversify this supply structure to not depend on any specific energy source since hydrogen can be procured from various forms of primary energy. This will significantly reduce energy procurement and supply risk. Diversifying energy imports creates opportunities for many trade alliances and agreements such as ones explored with Australia and the EU that could contribute towards Japan's hydrogen supply chain. This route mostly relies on the use of blue hydrogen, through which Japan plans to use CCS techniques to safely dispose of escaped carbon of steam-methane reforming into appropriate CCS project sites. Japan is also keeping overseas renewable energy in mind due to its rapidly declining price, meaning Japan could import it for green hydrogen production until its own renewable energy generation costs approach similar levels. Japan targets to achieve 30 JPY/Nm3 (normal cubic meter) by 2030 (Ministerial Council, 2017). At the same time, Japan will continue to expand its renewable energy sector to complement the rise of hydrogen energy generation.

Japan also plans to boost the commercial and industrial use of hydrogen to assist with the transition. The focus for promoting hydrogen energy among households lies in the popularization of FCVs and battery electric vehicles (BEVs). BEVs rely on lithium-ion batteries instead of hydrogen fuel cells, and although they are considered inferior to FCVs in terms of driving distance and recharging time, they are easier to produce. Both types of vehicles are expected to be rolled out to decarbonize the transport industry. For the industrial setting, Japan plans to move towards using fuel cells and co-firing hydrogen and ammonia at coal plants generate carbon-free energy (Ministerial Council, 2017). Co-firing is an energy generation technique that ‘incorporates a secondary fuel with a primary fuel utilizing the same combustion equipment’ (Gent, 2017). This technique lowers capital costs, increases operational efficiency and economies of scale, and lowers electricity costs due to the accommodation of two fuel types in the same plant (Kabalci, 2020), creating an opportunity reduce carbon emissions in a cost-effective way. In this instance, ammonia is preferred over hydrogen due to in co-firing with coal due to their compatible burning velocities (which helps streamline the combustion process) (Ministerial Council, 2017).

2.4.2 – Criticisms of Japan’s Basic Hydrogen Strategy

The Renewable Energy Institute of Japan released a report led by Teruyuki Ohno (2022) that criticized Japan’s hydrogen strategy and its progress made thus far. Regarding Japan’s push to promote the use of hydrogen energy in households, results have proved subpar. This is most evidently seen in the lack of sales of ENE-FARM units, a home-use fuel cell that supplies energy for a household. The Japanese government set a target of 5 million units to be sold by 2030, with only 433,000 units being sold by 2020. FCVs have suffered a similar trend, with only 5,170 units sold by 2020 when the government set a target for 800,000 units to be sold by 2030 (Ohno, 2022). The struggles are attributed to a combination of high costs and lack of model choices for consumers (Trencher, 2022). However, the Japanese government has put in significant effort to highlight the importance of hydrogen in the most recent Olympic games in Tokyo in 2021. Hydrogen energy was displayed in various areas of the event such as the deployment of 500 FCVs to transport the athletes and staff and the provision of 24 million kWh of electricity procured from hydrogen energy (Wang, 2021). Despite this push, this promotional strategy has proven to be a failure so far. Japan must identify an alternative of promoting hydrogen that will please both energy retailers and consumers to facilitate its spread.

Regarding Japan's plan to co-fire ammonia and hydrogen at coal plants, they are making significant strides forward in its implementation. JERA, Japan's largest power generation company, have plans to start testing a coal plant that co-fires 20% ammonia in 2023. While this strategy will be important in the decarbonization of the power plants, the rate of co-firing, even if increased to 50%, will prove to be insufficient in lowering emission levels. Moreover, even though ammonia does not produce CO_2 during combustion, it does during manufacturing, which offsets emission reduction. Finally, without an ammonia supply chain in place, it will be expensive and difficult to justify its continued use in co-firing (Ohno, 2022). Japan will need to identify an alternative that directly addresses emission reduction concerns.

Regarding Japan's plan to use hydrogen as a complement to aid the expansion of the renewable energy sector, Japan focuses on the use of blue hydrogen over green hydrogen, which does not directly address their emission reduction goals. While blue hydrogen does absorb CO_2 that is produced as a by-product of steam-methane reforming, there are no standards in place to deem its impact as acceptable for lowering emissions and is thus not recognized internationally as a legitimate decarbonization strategy. Additionally, with Japan's plans to import a mixture of gray and blue hydrogen from Australia to meet their set quota of 3 million tons of annual hydrogen production by 2030, concerns of the effectiveness of this strategy increases which Japan will need to address (Ohno, 2022).

This report states that although Japan's intentions are in the right place, the government approach their targets in ways that are not sustainable in an economic or financial sense. Ohno claims that the Basic Hydrogen Plan is "skewed" (Ohno, 2022) towards the use of hydrogen fuel cells as he highlights Japan's intense focus on the promotion of hydrogen fuel cells in areas such as vehicles and household appliances as a "bad idea" (Ohno, 2022). He claims that automobiles already have suitable options for decarbonization such as electrification while buildings can turn to cogeneration systems that combine heat and power to effectively reduce emissions. METI has stated that they plan to invest 460 billion JPY over the next ten years towards hydrogen integration, and if their strategy continues to align with the preference towards hydrogen fuel cells and Ohno believes that most of it will be wasted on pursuing this ineffective approach (Ohno, 2022).

2.4.3 – Public Suggestions to Improve Japan's Basic Hydrogen Strategy

Despite the criticisms levelled at the strategy, suggestions have been made regarding opportunities to increase its viability. Japan's Green Growth Strategy of 2020 states that the nation will require 20 million tons of hydrogen for their hydrogen energy transition by 2050 with the subsections being categorized as hydrogen power, hydrogen-based steel making, and commercial transportation. The Renewable Energy Institution highlights the need to refocus the strategy by comparing the use of hydrogen against other means of decarbonization under the premise of electrifying the energy demand (Ohno, 2022).

Next, the Renewable Energy Institute suggests that the hydrogen strategy should focus on building a reliable hydrogen supply chain that focuses on green hydrogen. The Basic Hydrogen Strategy aims to expand its use of hydrogen with little consideration of the harm of using polluting forms of hydrogen such as gray and blue. Therefore, the strategy should solely build on the use of green hydrogen. While producing domestic green hydrogen is expensive, it is expected that renewable energy prices in Japan will fall drastically until 2050 which will help reduce the production cost of hydrogen energy. Japan could slowly transition from the importation of green hydrogen to producing it themselves. This would also increase Japan's energy self-sufficiency rate which currently rests at 12% (Ohno, 2022). A side-by-side development of a hydrogen supply chain and the renewable energy sector in Japan would complement both sides, lowering the price of hydrogen production and allowing for the long-term storage of intermittent renewable energy.

2.5 – Conceptual Framework

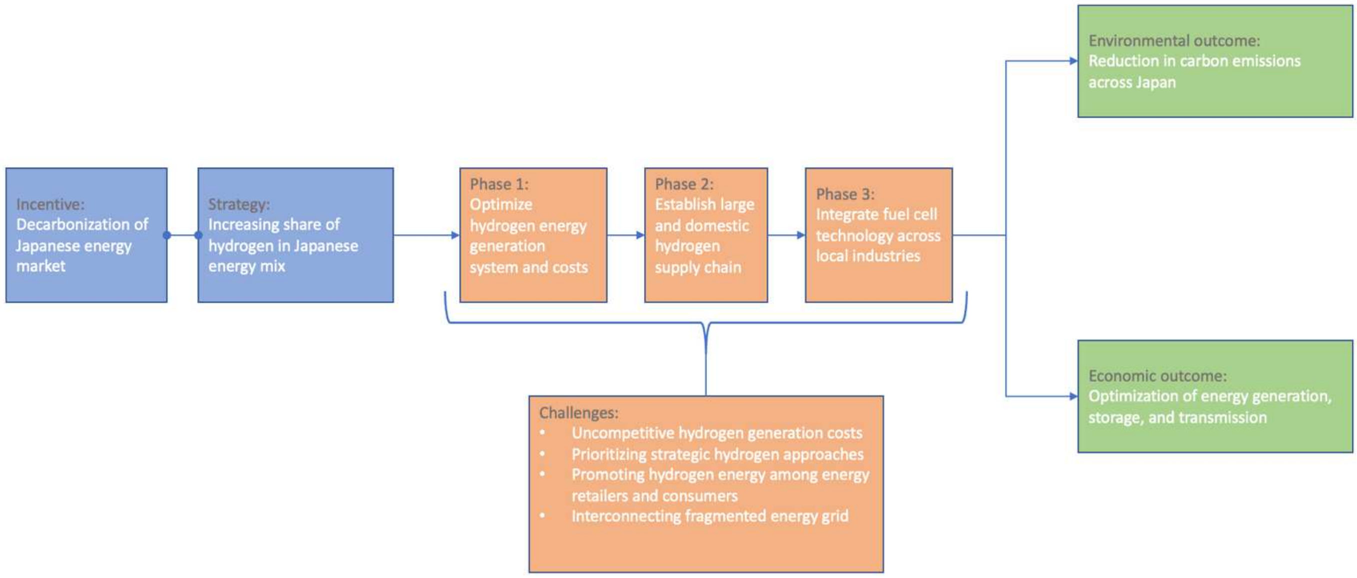


Fig. 12: Conceptual framework

As outlined in the framework, Japan's hydrogen strategy will be key to unlocking a variety of goals that will improve their energy sector and overall economy. The literature review has shown areas where Japan faces threats and opportunities for their plan to increase the share of hydrogen in Japan's energy mix. The conceptual framework is strategically divided into phases to ensure the transition is not rushed and proceeds smoothly. The framework also outlines challenges that the hydrogen strategy must keep in mind throughout to avoid failure. The outcomes seen at the end of the framework demonstrate the widespread national benefit that Japan would experience if the hydrogen strategy were conducted appropriately.

The conceptual framework will serve as the basis from which my research and discussion will be conducted. Continuing in the thesis, the text will address the criticisms of the Japanese Basic Hydrogen Strategy to recommend a viable route for the integration of hydrogen in the Japanese energy market.

3 – METHODOLOGY

3.1 – Research Method and Design

The purpose of this research is to investigate a viable method through which hydrogen energy can be integrated in the Japanese energy market in an economically and environmentally beneficial way. As this topic relies on a foundation of feasibility to pursue, quantitative research will be conducted to procure data on the ongoing operations relating to Japan's current hydrogen strategy. However, the use of hydrogen in an energy market is a relatively new in Japan's energy sector. To provide additional perspective that shines light on the subject from within the Japanese energy sector, qualitative research will be conducted.

3.2 – Data Collection Procedures

In this section, the methods of data collection and the criteria of source selection will be discussed.

3.2.1 – Quantitative Research

The quantitative research will procure data regarding the status of Japan's energy market and current hydrogen strategy. The data will be derived from relevant research papers and the Japanese government. The research papers will focus on predictions made based on the status of Japan's hydrogen efforts and the information from the Japanese government will relate to the logistics of their current operations. This research was conducted like the literature review by relying on secondary research to acquire a structured set of data and knowledge. As such, only sources published after the release of Japan's Basic Hydrogen Plan will be considered to maintain relevancy while other criteria such as the methodology, the sources of the research, and the consideration of any existing critique from other studies that may contradict a source's content will all be considered when retrieving data. In later sections, this data will be analyzed to gauge the viability of the current hydrogen integration strategy and then contrasted against the Japan's energy policy ideals to identify an economically and environmentally beneficial method of integration.

3.2.2 – Qualitative Research

The qualitative research will procure additional insight to guide the exploration of Japan's hydrogen strategy. The research will be conducted through a semi-structured interview with a professional in the Japanese hydrogen fuel cell sector. A semi-structured interview was selected for this section to be able to modify questions to accordingly facilitate discussion and allow the interviewee to elaborate on their answers.

To ensure that the information derived from the interview is as relevant as possible, I have selected a qualified individual within the fuel cell development team of Toyota, the largest and most successful FCV manufacturer in Japan, to discuss issues of FCV production and distribution to investigate possible solutions toward addressing the stagnant reaction toward fuel cell products among the Japanese population. Through personal connections, I was able to conduct an interview with Kohei Masaki, a hydrogen strategy consultant who has operated in both the North American and the Japanese division of Toyota. His responsibilities mainly lie in the business expansion of Toyota's fuel cell line, making him a relevant individual for the field of this thesis.

His interview was conducted in a one-on-one setting over Zoom and consisted of four sections that totaled up to eight questions. The first section focused on the supply-side concerns of FCVs, the second section focused on the infrastructure concerns of FCVs, the third section focused on the demand-side concern of FCVs, and the last section focused on the institutional concerns of FCVs. The interview was conducted and recorded in English and then transcribed. The interview questions and transcript can be seen in Appendix A and B respectively.

4 – FINDINGS

In this section, the findings of the quantitative and qualitative research will be outlined and framed to appropriately discuss the content.

4.1 – Desired Effects of Basic Hydrogen Strategy

The information retrieved from Table 1 can be used to investigate the structure of the Basic Hydrogen Strategy through the desired effects that the Japanese government had in mind when formulating the strategy. The information relates to a breakdown of the objectives and milestones of the strategy.

Table 1: Benchmark factors and targets of Basic Hydrogen Strategy (METI, 2019), (Ohno, 2022)

*FC = fuel cell

Benchmark Factors	2020 level	2030 target	2050 target

Source of supply	Domestic hydrogen production	International hydrogen supply chain and domestic electricity-to-hydrogen supply	CO2-free hydrogen (green hydrogen and blue hydrogen with CCS)
Annual volume (tons/year)	4,000	300,000	5,000,000 – 10,000,000
Cost (JPY/Nm3)	100	30	20
Transport applications (units) - **Hydrogen stations** - **FCVs** - **FC buses** - **FC forklifts**	 160 5,170 100 500	 900 800,000 1,200 10,000	Replace gas stations Replace gasoline vehicles Introduce large FCVs
Fuel cell utilization (Ene-Farm)	433,000	5,300,000	Replace traditional residential energy systems

The benchmark factors lay out the areas of the energy market that the Japanese government attempts to influence through the strategy. The strategy targets both the supply and demand side of the Japanese energy market.

In terms of supply-side, the strategy influences sourcing and production. For sourcing, the Japanese wholesale energy market will attempt to expand by developing international sourcing options. This expansion will be matched by a continuous development of a domestic hydrogen supply chain. These developments will remain on course until 2030 when priorities will shift towards strengthening local hydrogen production and its sustainable impacts. These sustainable impacts refer to the type of hydrogen produced, targeting zero carbon emissions through forms such as blue hydrogen that use CCS technologies that absorb carbon emissions and green hydrogen that doesn't release any. By 2050, the wholesale energy market will have grown to facilitate wide-scale hydrogen generation from both international and domestic sources. For production, the strategy optimizes the domestic production of hydrogen by simultaneously increasing its overall production level and lowering its costs. The local supply chain currently produces 4,000 t/year and targets 300,000 t/year by 2030 and upwards of 10,000,000 t/year by 2050. Hydrogen generation rates (sourcing from both domestic and international sources) are currently priced at 100 JPY/Nm3 (normal cubic meter) while targeting 30 JPY/Nm3 by 2030 and 20 JPY/Nm3 by 2050. The goal of this price optimization strategy is to push hydrogen generation costs down to 13 JPY/Nm3 which positions itself as a cheaper alternative to natural gas which is priced at 16.8 JPY/Nm3 (METI, 2019) to achieve grid parity. These aspects will render hydrogen generation as an economically appealing option compared to fossil fuels on top of its environmentally sustainable properties.

In terms of demand-side, the strategy aims to propagate the use of hydrogen across Japanese residents. For transport applications, the strategy aims to increase the number of active hydrogen-based vehicles. The line of hydrogen-based vehicles covers both civilian and industrial use. There are currently 40,000 FCVs, 100 FC buses, and 500 FC forklifts that are active. The strategy aims for 800,000 FCVs, 1,200 FC buses, and 10,000 FC forklifts by 2030 and eventually a complete transition from gas vehicles to hydrogen-based vehicles by 2050. To support this shift, hydrogen refuelling stations are set up to complement the use of FC vehicles. The 160 current refuelling stations aims to reach 900 units by 2030 with the goal of eventually replacing gas stations by 2050. Ene-Farm units similarly aim to spread, increasing from 1,400,000 active units to 5,300,000 units by 2030 and before eventually succeeding traditional residential energy systems by 2050. The culmination of these desired effects can be observed in this graphic from METI:

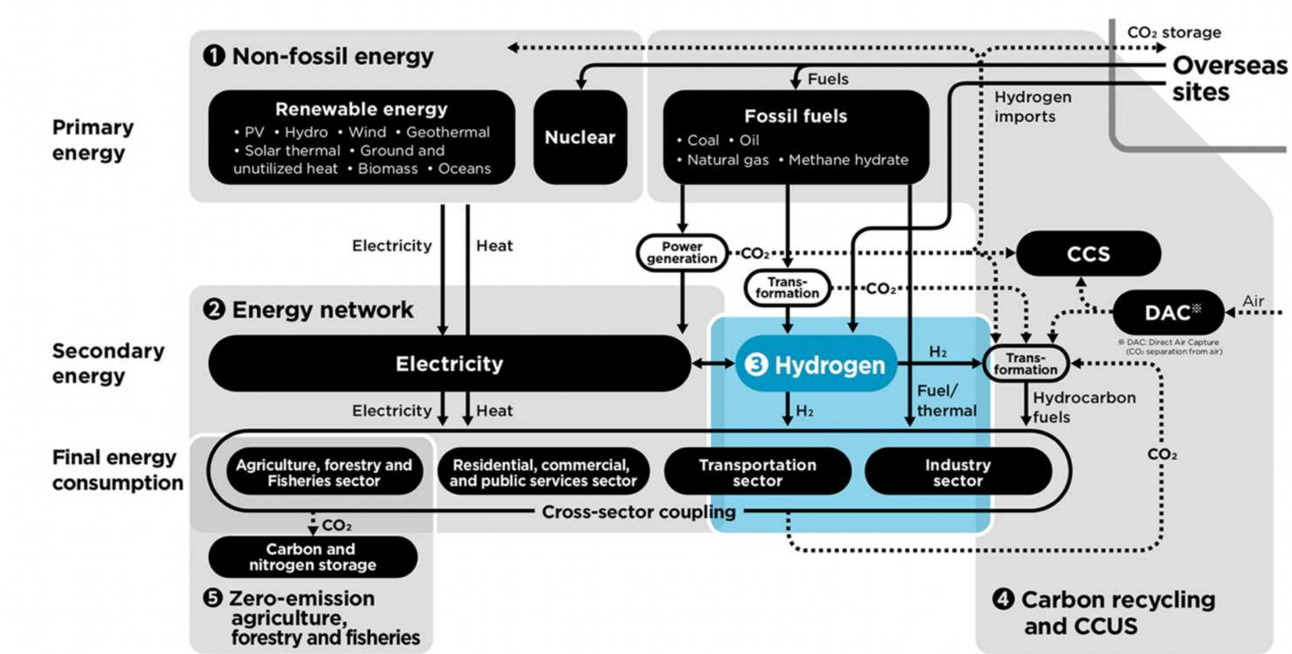


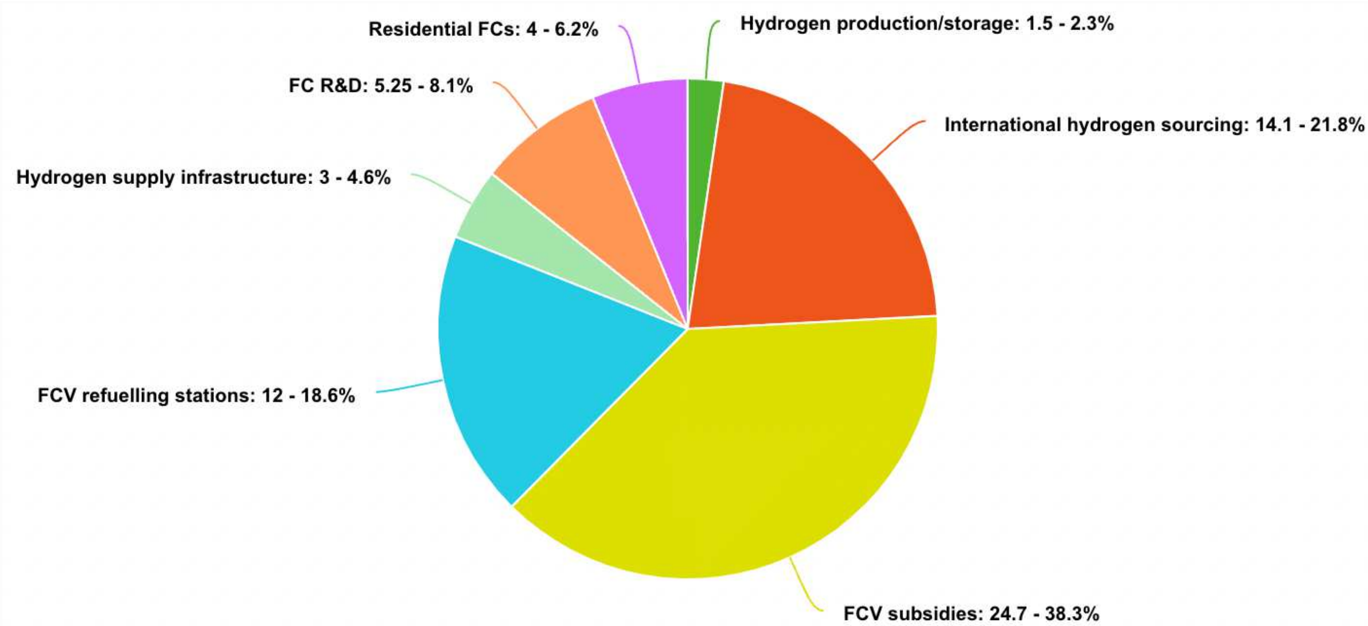
Fig. 13: Desired hydrogen-based Japanese energy market (METI, n.d.)

4.2 – Hydrogen Funding Allocation

With the general direction of the Basic Hydrogen Strategy established, Japan's funding for this project will be investigated. In 2022, the Japanese government released a breakdown of their fiscal year 2021 (April 2021 – March 2022) that showed their allocation of funding towards supporting the Basic Hydrogen Strategy. Additionally, the New Energy and Industrial Technology Development (NEDO), Japan's national R&D agency, released their ongoing projects in energy which are supported by funds provided by METI's Green Innovation Fund in 2021. The total amount of the Green Innovation Fund is 2 trillion JPY. The breakdowns can be seen in Charts 1 and 2.

Chart 1: Breakdown of Japanese government's hydrogen funding 2021 (Nakano, 2021)

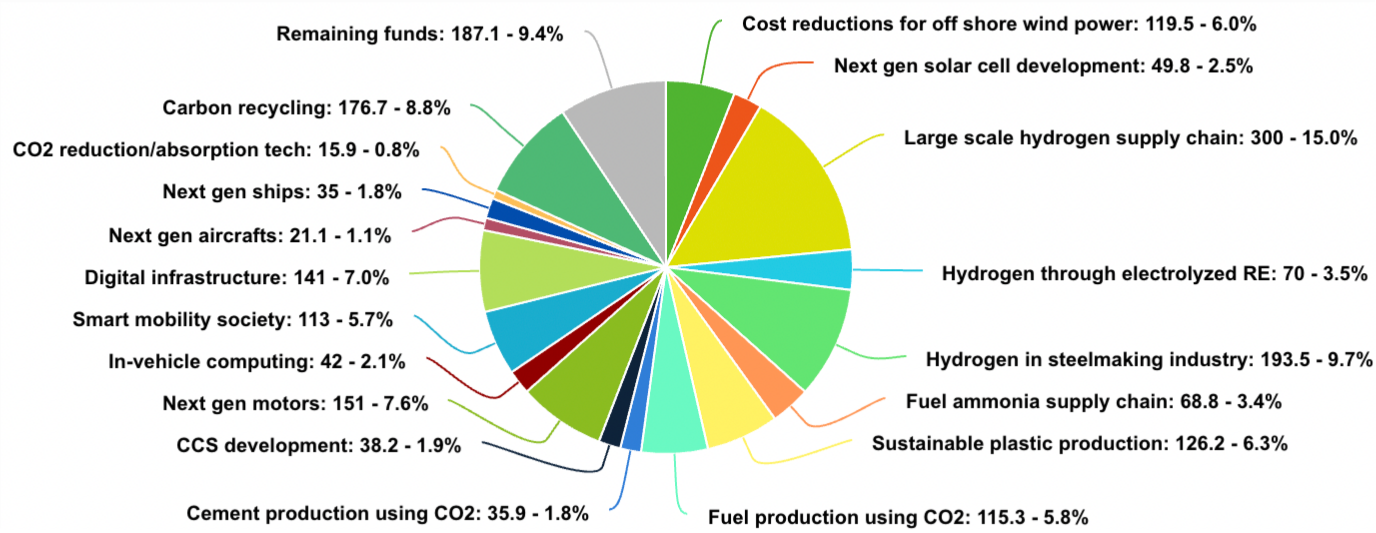
*All values are in billions of JPY



The distribution of Chart 1 indicates a strong focus on the demand-side of hydrogen integration as FCV investments collectively take up 54.9% of the government's hydrogen funding. Hydrogen supply chain development assumes a secondary goal as it collectively takes up 26.4% of the budget. Other areas such as FC R&D, hydrogen production/storage, and residential FC technology consume the remaining 18.7% of the budget.

Chart 2: Breakdown of NEDO project fund allocation 2021 (METI, 2022)

*All values are in billions of JPY



The distribution of Chart 2 indicates NEDO's high priority for hydrogen integration as its collective investments take up 31.6% (includes large-scale hydrogen supply chain, hydrogen through electrolyzed RE, hydrogen in steelmaking industry, fuel ammonia supply chain) of the Green Innovation Fund. It should be noted that these investments strongly support the supply-side development of hydrogen such as supply chain development rather than demand-side areas. Significant funding is also allocated for projects that indirectly support the integration of hydrogen such as carbon recycling and CCS development (that develops the production of blue hydrogen) and next generation motors (that assist the innovation of FCVs). The remaining projects that are unrelated to hydrogen take up 40.9% of the Green Innovation Fund while 9.4% of the 2 trillion JPY remains unused for any future projects. The breakdown of funding for hydrogen integration in Japan shows an emphasis on its supply-side development.

4.3 – Simulated Effects of Basic Hydrogen Strategy

In consideration of the targets set by the Basic Hydrogen Strategy, a model will be used to evaluate the long-term changes in Japan's hydrogen demand and supply heading into their 2030 and 2050 targets. A long-term intertemporal optimization energy model, the Global Relationship Assessment to Protect the Environment (GRAPE) model initially designed by Kurosawa (2004), will be used for this purpose.

This model serves to analyze the relationship between energy markets, the economy, climate change, and land use. On basic terms, the GRAPE model operates by estimating energy demands from projections of population, GDP, and other energy-related statistics. Then, possible energy technologies and innovations are considered (in this case, hydrogen). From this data, the model simulates an energy demand-supply structure that minimizes costs while satisfying energy demand in all sectors under certain constraints such as limiting CO2 emissions (Ishimito, 2017). In a study conducted by Chaube et al. (2020), the GRAPE model was used to simulate outcomes of the development of hydrogen in the Japanese energy market given the government's budget and benchmark targets for 2030. The data split into 4 key sectors can be observed in Table 2.

Table 2: GRAPE model outcomes of hydrogen in Japanese energy market (Chaube, 2020)

*Kyushu is Japan's southern-most region

Key Sector	Modelling Outcomes (target 2050)
Storage	- 1000-2500 GJ/month using renewable energy-based electrolysis in Kyushu prefecture - Increase renewable energy to 59% of national energy supply, 13% total from hydrogen
Gas grid	- 34% of gas heating load in Kyushu - Multi-household use FCs mitigate household emissions - 272.14 GJ of hydrogen per annum blended with city gas
Power generation	- Importing hydrogen at 30-40 JPY/Nm3 leads to 22%-50% of electricity generation from hydrogen - Domestic hydrogen production leads to 25% of electricity from hydrogen, while up to 50% can be attained with import prices at 20-35 JPY/Nm3

	- 600TWh of hydrogen (55% of generation mix) using mix of domestic/international sources leads to energy costs 8.2-13.8 JPY/kWh - 200TWh of direct hydrogen combustion combined with 25 GW nuclear capacity leads to energy costs 11.1-12.5 JPY/kWh
Transport	- 40% of Japanese transport sector driven by hydrogen - 19% of new vehicle sales in Asia - 25% of freight sector transition to FCEVs - Share of light-duty FCVs is 20% and FC trucks is 57% - 8.5x growth in FCV sector between 2008-2050 - 238.65 GJ of hydrogen per annum for 3.7 million FCVs

In terms of energy generation and storage, the long-term integration of hydrogen energy is simulated to increase the capacity of renewable energy in Japan to 59% with the specific use of hydrogen supplying 13% by preserving the intermittent energy generation of renewable sources such as solar and wind energy.

In terms of gas grid supplementation, it is simulated that hydrogen could contribute up to 34% of the gas heating load in the Kyushu region. Gas grid supplementation occurs through the blending of hydrogen with gas networks for reforming. With appropriate policy implementation to maximize energy market penetration, it is predicted that 272.14 GJ of hydrogen can be blended with gas to help mitigate greenhouse gas emissions.

In terms of power generation, the pursuit of reduced hydrogen energy prices can lead to the realization of greater shares of renewable energy in the national energy generation mix. The achievement of 20-40 JPY/Nm3 supports the potential 59% of renewable energy supply in Japan. The pursuit of utility-scale hydrogen that combines domestic and international energy sources could lead to the generation of 600 TWh of hydrogen in the range of 8.2-13.8 JPY/kWh.

In terms of transport, it is shown that with proper policymaking, the transportation sector can be greatly influenced. By 2050, FCVs could lead 19% of vehicle sales in Asia with FCVs comprising 25% of the freight transport sector. This would result in FCVs taking up 20% of light-duty vehicles in Japan while FC trucks would comprise 57% of the national fleet. In terms of passenger vehicles, the total quantity of hydrogen to be set aside would be 238.65 GJ to satisfy the use of 37 million FCVs which represents roughly half of the 2017 passenger fleet.

The simulated effects according to the GRAPE model of hydrogen integration show immense positive change in Japan's energy market and heightens the necessity to refine the strategies to do so.

4.4 – Pursuing a Hydrogen Supply Chain

Due to the heightened domestic prices of hydrogen production, the Japanese government is initially looking outwards to develop an international hydrogen supply chain to kickstart its integration in the Japanese energy market. International energy import prices and their viability in terms of cost-competitiveness can be seen in a study conducted by Kan and Shibata (2018).

Only three sources achieve adequate cost-competitiveness to match against Japanese oil-fired thermal plants: Canadian hydropower, New Zealand's hydropower, and China's hydropower. While most international sources compete on relatively similar costs for delivery, transportation, liquefaction, among other aspects, these three are cost leaders in terms of production costs, making them appealing for importation for Japan. However, no renewable international source thus far achieves low enough pricing to meet METI's 2030 target for hydrogen energy at 30 JPY/Nm3.

Japan has already pursued the formation of a stable international hydrogen supply chain with various countries. However, it must be noted that their current projects rely on CCS technology to produce blue hydrogen as it is cheaper than producing green hydrogen, meaning it is not a fully sustainable process. Their ongoing projects can be seen in Table 3.

Table 3: International hydrogen supply chain projects based in Japan (Okunlola, 2022), (Clifford Chance, 2022), (Kimura, 2020)

Country	Active Since	Method of Transport	Form	Output (t/year)	Hydrogen Cost (JPY/Nm3)
Brunei	2020	Hydrogen is converted into MCH through hydride technology for shipping before dehydrogenation at arrival	Blue	210	100
Australia	Projected for mid 2020s	Hydrogen is extracted from brown coal and then liquefied for shipping and then stored at arrival	Blue	225,540	29.7
Canada	Projected for early 2030s	Hydrogen is converted into ammonia for shipping and then stored at arrival	Blue	165,000	59.8

The only active project within those mentioned in Table 3 is the supply chain shared with Brunei. The first successful delivery of hydrogen through this supply chain was performed in 2019 with continuous operation beginning in 2020. The output of this agreement is expected to expand beyond the current shipping rate of 210 t/year at 100 JPY/Nm3 as Japan aims to increase its level of hydrogen importation (NYK Line, 2020). The other two projects mentioned, conducted with Australia and Canada, are both yet to function. However, the supply chain coordinated with Australia is much more advanced in its project life cycle. The first shipment to Japan occurred in 2022 with full operations expected to start in the mid 2020s. The projected shipping rate is 225,540 t/year at 29.7 JPY/Nm3 which greatly improves on the output and cost of the supply chain with Brunei due to the large supply of brown coal in Australia's possession (HySTRA, n.d.). The supply chain agreed with Canada is the most speculative now, but plans exist to form an agreement that would see 165,000 t/year at 59.8 JPY/Nm3 of hydrogen go to Japan.

Moreover, the Japanese government aims to support a domestic hydrogen supply chain to supplement their hydrogen importation. The infrastructure for such a system is still in development with major domestic companies planning to roll out production operations in the next few years. The Ministry of the Environment (MOE) currently backs a few projects led by local energy businesses to develop a local hydrogen supply chain. Some of these companies include Toyota, Hitachi, the Daigas Group (Ministry of the Environment, 2021). Currently, there is no stable supply of hydrogen being produced locally that is being provided by these electric companies. However, as seen in Charts 1 and 2, there is funding that supports the domestic production of hydrogen which will impact the supply infrastructure in the coming years.

4.5 – Propagation of FC Technology in Japan

The information relating to the distribution and acceptance of fuel cells across the Japanese population can be gleaned from the interview conducted with Kohei Masaki. The full transcript of the interview can be seen in the Appendices.

As outlined in the literature review, FCVs have struggled to become popular among the Japanese population as evidenced by subpar sales figures. There are numerous factors behind this trend, but high production costs that hamper the mass manufacturing process of FCVs are attributed as one of the primary ones. Masaki discusses this concern in relation to the competition between FCVs and EVs, mentioning many of the benefits of FCVs explored in the literature review that show how they can compete with EVs despite the higher production costs. Masaki also highlights certain strategies that Toyota are implementing to reduce FCV production costs to increase their competitive advantage in the passenger vehicle market. Common production practices are suggested such as scaling up production volume, streamlining production processes, increasing R&D investments, collaborating with other suppliers. Masaki highlights that these practices will have significant long-term impacts on Toyota's ability to produce and sell FCV units.

> "Most of these strategies may seem quite standard, but the recent introduction of hydrogen fuel cell technology means that large advancements can be made that greatly optimize both the supply and demand of FCV units." (Masaki, 2023)

Masaki underlines that the successful propagation of FCVs in Japan not only relies on the distribution of FCVs themselves, but the establishment of a stable infrastructure for hydrogen to thrive in. He highlights the importance of collaboration with other participants of the Japanese energy market to create a unified network that shares building and operating costs of a local hydrogen supply chain system. This system can be supported by innovating business and financing mechanisms that lowers these costs across the board and optimize the overall performance of the domestic hydrogen supply chain system. Masaki also discusses Toyota's involvement with the Hydrogen Utilization Promotion Council (HPC), a worldwide initiative that elevates hydrogen as the focus of energy transition (Hydrogen Council, n.d.).

> "In order to plan the building and management of hydrogen stations as well as to create technologies and standards for hydrogen production, storage, and transportation, the HPC collaborates closely with electric companies and retailers." (Masaki, 2023)

Masaki discusses strategies employed by Toyota to facilitate the rollout of hydrogen refuelling stations, highlighting the need for an efficient and flexible model to be effective. Collaboration with stakeholders, particularly local energy companies, automakers, and governments is prioritized to promote a healthy infrastructure for hydrogen. The optimization of this system is supported by Toyota's data-driven approaches that compute effective location planning strategies for stations. These data-driven approaches also form the basis for their modular station design.

> "(The modular station design) enables us to construct stations gradually, lowering initial costs while ensuring that we can expand rapidly as demand rises." (Masaki, 2023)

Masaki also highlights the importance of addressing the demand-side issues of spreading FCVs. He discusses the initial market segmentation and profiling conducted by Toyota that helped them identify key audiences such as early adopters as well as corporate and government fleets, all of which target a high degree of sustainable operation. Masaki also mentions urban targeting and the use of promotional campaigns to support marketing efforts. New business models were also explored that provide added incentives to consumers for FCV ownership.

> "-- we are exploring ways to lease the fuel cell stack to customers, rather than selling it outright. This can help to lower the initial purchase cost of the vehicle and make it more affordable for consumers." (Masaki, 2023)

Masaki touches on the psychological aspects of FCV adoption in Japan in relation to the resistance that the product has faced in the Japanese population. He mentions commonly held public concerns such as high costs, refuelling issues, reliability concerns, and narrow product lines that decrease the appeal of FCVs. However, many of these concerns are addressed by Toyota to reassure consumers of the quality of FCV models. Masaki also makes sure to highlight the knowledge of consumers as a primary psychological barrier that Toyota must work towards overcoming. The recency of hydrogen fuel cell technology means that many consumers may be unaware of its properties and benefits. Masaki discusses

Toyota's investments in promotional campaigns, corporate partnerships, and media coverage that aim to increase the familiarity of FCVs to the Japanese public. Test-drive events are also coordinated to increase consumer engagement.

> "People can test FCVs at these events and learn more about their capabilities and environmental advantages. The ability of test drives to increase awareness among prospective customers who might be reluctant to adopt new technologies..." (Masaki, 2023)

Lastly, Masaki addresses the institutional barriers that Toyota must work with that restrict their potential for employing a successful FCV system in Japan. The lack of hydrogen infrastructure and the complex and unrefined regulatory environment for hydrogen, both borne from the recency of hydrogen fuel cell technology in Japan, have caused difficulties for Toyota to operate freely. Masaki highlights Toyota's initiatives in improving the playing field through municipal action that aim to address these difficulties.

> "In addition to pushing for industry norms for hydrogen fuelling, we have been advocating for changes to laws governing hydrogen production, storage, and transportation." (Masaki, 2023)

Overall, while the resistance to FCVs is evidently strong and requires great efforts to overcome, the interview with Masaki has shown efforts can be made both on the supply and demand side to make advances in the spread of FCVs in Japan.

5 – DISCUSSION

In this section, the findings observed in the previous section will be discussed and evaluated against the contents of the literature review and other relevant texts. This section will also address the third research question, "How can Japan reconfigure their strategy for hydrogen integration to effectively achieve an economically viable and environmentally considerate energy market?”

5.1 – Hydrogen Supply Chain Development

Developing an advanced hydrogen supply chain system has been a forefront of Japan’s strategy to integrate the energy carrier into their energy market. As established in the research conducted, these efforts have been split between developing both an international supply chain for importing hydrogen and a domestic supply chain that converts locally generated energy into hydrogen. Both will serve important roles in ensuring a stable supply of hydrogen in the nation.

5.1.1 – International Hydrogen Supply Chain

While not fully operational, Japan has shown clear advances in developing an international hydrogen supply chain through the arrangements made with Brunei, Australia, and Canada so far. Imports from these nations will heavily increase the inflow of hydrogen into Japan, totaling up to 390,750 t/year and potentially more with agreements for additional links in this supply chain with other nations in the works. While this figure does surpass the desired target of 300,000 t/year and even the Australian hydrogen imports achieving a lower unit price than the 2030 target at 29.7 JPY/Nm3, it must be noted that these imports are based in blue hydrogen. Blue hydrogen may have its benefits over gray hydrogen through its possibilities of decarbonization through CCS technology, it is not fully reliable or effective. Howarth and Jacobson (2021) have explored the use of blue hydrogen in a decarbonized society and conclude that there is no existing commercial technology that sustainably stores carbon that is captured from the production of blue hydrogen, rendering it more of a distraction rather than a solution towards achieving decarbonization. As such, Japan’s plans for an international hydrogen supply chain will not lead to an environmentally clean energy system due to its reliance on blue hydrogen. To truly create a sustainable hydrogen supply chain, Japan must prioritize the cleanliness of their hydrogen imports rather than their cost to achieve their targets for sustainability. As the Renewable Energy Institute suggested, the priority should remain with sourcing green hydrogen.

Chart 3: Supply costs of renewable hydrogen energy (Kan, 2018)

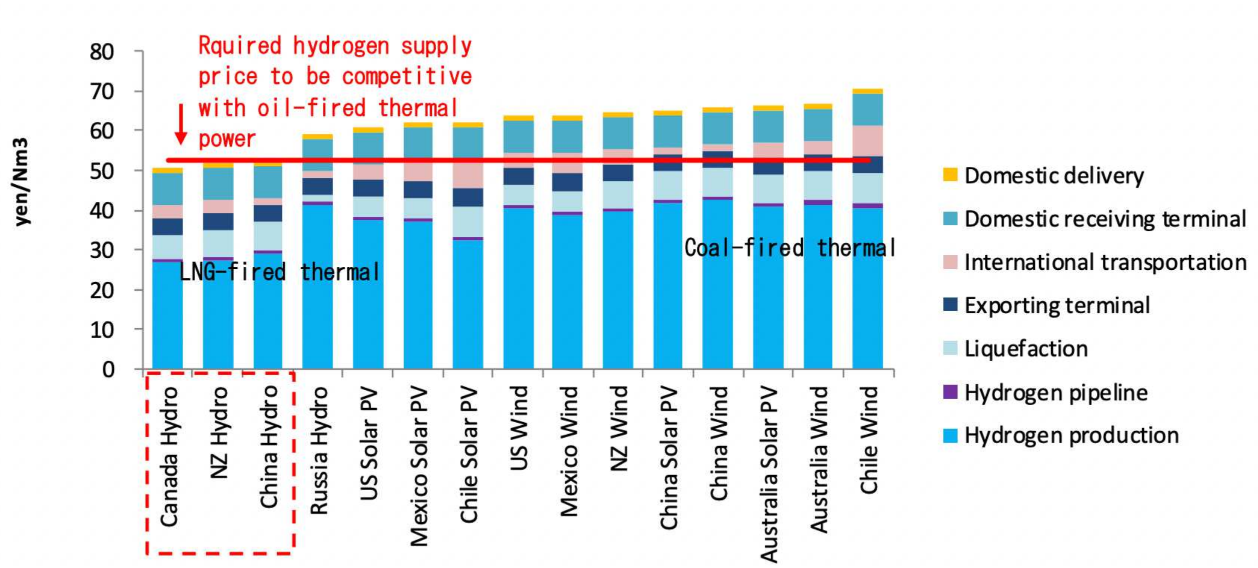
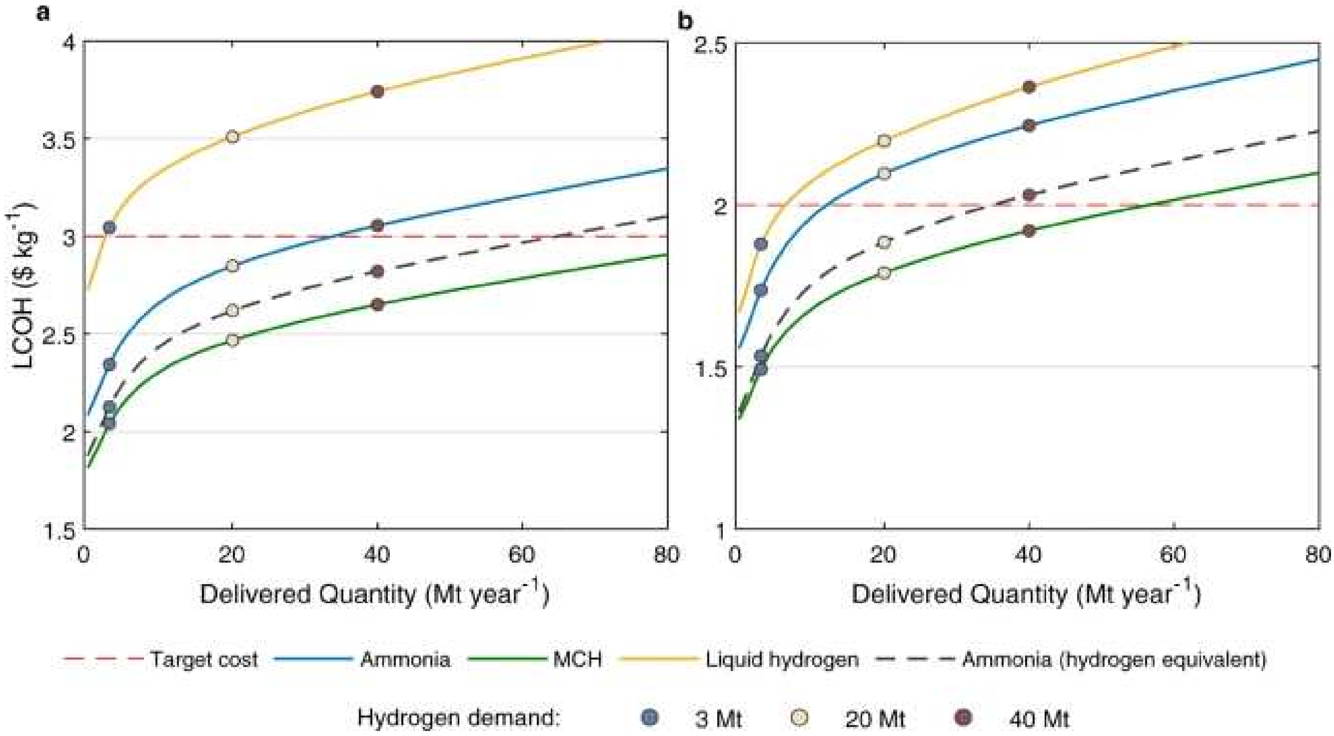


Chart 3 displays the collective import costs of renewable energy sources around the world for Japan. As seen, there are many avenues to explore apart from the projects agreed with Brunei, Australia, and Canada. Particularly, renewable energy sources from Canada, New Zealand, and China have shown to achieve costs at a level where they can firmly compete with oil-fired thermal power. Currently, their costs hover around 50 JPY/Nm3, but with time and innovation, these renewable energy sources among others can become reliable and affordable sources of international hydrogen.

Another supporting factor for creating a sustainable and affordable hydrogen supply chain is the financial support behind its development. While there is significant investment behind these projects, such as the 45 billion JPY jointly funded by NEDO and the Australian government (Global Australia, n.d.), the funding allocation from the Japanese government suggest strong preference towards the development of FCVs in Japan since 56.9% of their yearly budget for hydrogen integration is dedicated to that cause while 21.8% is allocated towards international hydrogen sourcing. The sheer size of projects relating to international hydrogen sourcing requires a high degree of coordination across countries and continents and thus should receive stronger financial support. Readjusting the funding allocation in favor of developing a supply chain would help drive down costs and lead to sustainable and affordable importation of hydrogen.

One opportunity for Japan to pursue that would appropriately redirect their plans for an international hydrogen supply chain would be the importation of green hydrogen created from offshore wind production in China. Over the past few years, China has looked to capitalize on their coastlines with shallow water depths (>60 meters) that provide a favorable environment for offshore wind energy generation. These conditions can contribute to significant cost reductions in energy generation, making it an affordable and sustainable energy source. Feasibility reports conducted by Sherman et al. (2020) estimate that this energy source could generate 12 petawatts of energy annually, an amount that represents four times the projected wind energy demand for China by 2050. Additionally, with hydrogenation technology that is expected to achieve great strides in cost (see Charts 4 and 5) and operational efficiency (targeting to lower energy requirement for hydrogen liquefaction from 12 kWh/kg to 3.9 kWh/kg) over time, this arrangement becomes very appealing for Japan to pursue. A study conducted by Song et al. (2021) uses a cost-optimization model written using Release 2020b of the MATLAB and Simulink product families to provide a grid-by-grid analysis of offshore wind deployment, for the operation of electrolysis equipment, for hydrogen conversion, for energy storage, and for related overseas transportation. The model provides supply curves for the cumulative quantity of three forms of imported hydrogen (methylcyclohexane (MCH): a compressed, gaseous form of hydrogen, ammonia, liquid hydrogen) against the levelized cost of hydrogen (LCOH) for the two target dates of 2030 and 2050.

Chart 4 and 5: Supply curves for offshore wind produced in China and delivered to Japan, 2030 and 2050 targets (Song, 2021)



As seen in Charts 4 and 5, hydrogen transported in the form of ammonia and MCH achieves and even surpasses the target costs set by the Japanese government at both 2030 and 2050, exemplifying its potential as a source of imported green hydrogen. The potential to import amounts as large as 40 Mt/year (40,000 kg) shows that this arrangement can satisfy a significant portion of Japan's target output for hydrogen (300,000 kg/year by 2030). This output can be transported in a few ways, such as the use of liquid organic hydrogen carriers (LOHCs) used in the hydrogen supply chain system shared between Japan and Australia. However, Van Wijk and Wouters (2021) suggest that an underwater pipeline could be constructed between the two countries due to their relative proximity to transport hydrogen. Costs will have to be assessed for this opportunity, but it could serve as an additional path for cost optimization for this project.

The agreement of such a supply chain between China and Japan would not only serve to progress Japan's ambitions for hydrogen-driven decarbonization, but it would strengthen the trade relationship between them. By sourcing funds from investors of both countries, the costs of developing this supply chain can be shared and rendered more affordable.

This potential project shows the viability of a sustainable and affordable hydrogen supply chain. While prioritizing the cost-competitiveness of hydrogen imports in the form of blue hydrogen is indeed important in terms of economic feasibility, doing this will lead to the development of projects that will serve no long-term environmental benefits that Japan is chasing. Supply chains based in blue hydrogen lack the technological innovation to be carbon-neutral and will therefore cause detours in Japan's plans for decarbonization. Keeping an emphasis on the sourcing of green hydrogen will lead to environmentally beneficial projects, after which, investments can be made to optimize and reduce the costs of the supply chain to create cost-competition. Japan should reevaluate their active agreements with Brunei, Australia, and Canada and focus on the importation of green hydrogen rather than blue hydrogen and refining their CCS technology.

5.1.2 – Domestic Hydrogen Supply Chain

Japan's domestic hydrogen supply chain has not achieved the same advances as its international counterpart in recent years. As seen in Chart 1, the Japanese government has directed significantly more funding towards international hydrogen sourcing, taking 21.8% of their yearly hydrogen budget, while local developments of a hydrogen system are seen through the funding allocations of hydrogen production and storage (2.3%), and hydrogen supply infrastructure (4.6%), which collectively take up 6.9% of Japan's yearly hydrogen budget. This favorability expressed towards the development of an international hydrogen supply chain system is understandable to an extent, as the volume of hydrogen to be imported has much greater potential collectively across multiple supply chains compared to everything that can be produced locally in Japan. However, it is imperative that Japan continues developing their domestic infrastructure for a variety of reasons. Not only will locally made hydrogen help with many domestic projects such as Toyota's efforts in spreading

FCVs across Japan, but it would also encourage domestic energy generators and retailers to move towards producing and distributing hydrogen-based energy and unify the Japanese energy market to support hydrogen. Finally, continuing the development of a local hydrogen supply system will help address a major concern of the Japanese energy market, that being their relatively low self-sufficiency rate which currently rests at 12%. According to the Lowy Institute Asia Power Index (2023), Japan is ranked the second lowest country for self-sufficiency. Improving their domestic energy supply through locally produced hydrogen can increase this rate and therefore allow Japan to rely less on other countries for energy imports. Relying on energy imports can be dangerous because this means that Japan's energy supply can be influenced by international situations out of their control which jeopardizes their energy stability: a key issue that METI aims to overcome. Having considered the benefits of developing a domestic hydrogen supply chain, some of Japan's current efforts will be reviewed.

Many of the projects for developing a domestic hydrogen supply chain in Japan start as an agreement made between several businesses across different energy-related industries which is approved and financially supported by NEDO. One such example of this arrangement can be seen in Hokkaido, the northern most region of Japan. In October 2022, the ENEOS Corporation, Hokkaido Electric Power Co., Inc., JFE Engineering Corporation, Hokkaido Electric Power Network, Inc., and Deloitte Tohmatsu Consulting LLC agreed on a joint study for the establishment of a large-scale green hydrogen supply chain system in the region (JFE, 2022). They approached NEDO and received approval for the backing of their project, and their project is currently ongoing in its logistical analysis. Hokkaido was chosen as the area of study considering its rich potential in renewable energy resources such as solar and wind power. However, the region has experienced difficulties in drawing out the full potential of this energy due to the relatively small electricity demand of Hokkaido. These issues combine to create a situation in which there is often an excess of renewable-based electricity being generated that goes to waste. To solve this issue, a hydrogen infrastructure is being developed to harness the renewable energy generated in Hokkaido. Water electrolysis is expected to be used as the base of this project due to its effectiveness in adjusting the electricity load through changing the production volume of hydrogen. The aim of this project is to test the feasibility of a domestic hydrogen supply chain that produces hydrogen at a rate of 1,000 t/year. If carried out, this would represent the largest site of hydrogen production in Japan. On top of hydrogen production, this study will also explore techniques for excess electricity utilization. The project aims to achieve technological verification by 2030 with full-out operation to occur soon afterwards (JFE, 2022). This project shows great promise and effectively turns a problem: excessive and intermittent renewable energy, into an asset: preserved renewable energy in the form of hydrogen.

Despite there being many ongoing projects like this that are backed by organizations like MOE and NEDO, they are quite isolated and lack connectivity and continuity with each other. Projects such as this one in Hokkaido only serve to address the energy concerns in the local area without contributing much on a national scale. A solution to address this issue would be to prioritize the connectivity of these projects with the main energy grid system of Japan. As seen in Fig. 2, the national energy grid is quite fragmented due to its initial division into 10 individual sectors as well as the difference in frequency between its Eastern and Western halves. These conditions make it difficult to transfer electricity between different regions across Japan due to the coordination required between each sector's ISO and the frequency conversion required at the cycle boundary. In the case of the hydrogen supply chain project in Hokkaido, it would experience far greater success if the project also focused on grid interconnectivity so that it could transfer electricity produced from its renewable sources to other areas of Japan instead of storing excess electricity for an area that already possesses a low energy demand. This strategy would allow domestic hydrogen supply chain projects to capitalize further on the intermittent production of renewable energy sources and reduce the need for developing hydrogen storage units while effectively distributing the excess energy across the nation. This development would require the national energy grid to achieve continuity which is a goal outlined by METI in their 6th Strategic Energy Plan published in 2021 (METI, 2022). METI considers the constraints that renewable energy faces in Japan and works towards optimizing the national energy grid by 1) reinforcing transmission lines to increase capacity and 2) sophisticating existing power grids to utilize transmission lines. To accommodate for these individual projects backed by MOE and NEDO, METI should collaborate with them and the project leaders to provide stronger and more consistent transmission connectivity across energy grids. This would increase the interconnectivity of the individual hydrogen supply chain projects across the country and work towards establishing a large-scale domestic system. Hydrogen project interconnectivity can be further increased through the repurposing of natural gas pipelines to serve hydrogen transmission. This has already been observed in European hydrogen pipelines (Hydrogen Europe, 2022) and can lead to the blending of gas and hydrogen to fuel energy grids as observed in Table 2 with potentially 272.14 GJ of hydrogen being blended with city gas in Kyushu's energy grid.

Additionally, as Masaki points out in his interview, there are major institutional barriers that prevent the growth of domestic hydrogen supply chain projects. The lack of industry norms and national policies relating to the use of hydrogen create many difficulties and delays for these projects since hydrogen is naturally categorized as a substance under the High-Pressure Gas Safety Act and is therefore treated as a dangerous, flammable gas with strict safety measures (CMS, 2021). These regulations, pertaining to the manufacturing, storage, transportation of hydrogen, are generic and aim to safely handle all forms of high-pressure gas in Japan. However, the importance of hydrogen in the coming years should signal that it requires its own regulatory framework with its own specific set of that reduces the number of unnecessarily strict regulations it faces (because of being grouped with dangerous high-pressure gases such as acetylene (Kanazawa University, 2020)), allowing domestic supply chain projects to proceed much more smoothly. This would lead to shorter project times and greater rates of success.

Finally, a complementary strategy, like what was suggested for the development of an international hydrogen supply chain, would be to readjust the funding allocation for hydrogen integration in Japan and create a stronger focus on the backing domestic projects. As mentioned, although hydrogen imports will bring in a significantly larger volume than domestic production, a larger portion of the budget should focus on local projects to ensure that Japan will not rely entirely on imports to sustain a hydrogen economy and lower their self-sufficiency rate.

With these developments on both the international and domestic scene, Japan's plans for a widespread hydrogen supply chain system can achieve the accomplishments seen in Table 2. The increase in the volume of hydrogen in Japan would readjust the national energy generation mix to increase the share of renewable energy to 59% with hydrogen energy taking up 13% of that share. This creates large advances for Japan's efforts in decarbonization and addresses their self-sufficiency issues. In combination with the development of their renewable energy sector, innovations in the field can lead to greatly reduced prices for hydrogen generation that go as low as 11.1 JPY/kWh. Across the nation, up to 272.14 GJ of hydrogen-based energy can be blended with city gas to create a mixed energy grid that continues to transition to fully renewable operations. Advances in both Japan's domestic and international hydrogen supply chains are crucial for the results of the GRAPE simulation to become reality, with the international side responsible for bringing in most of the volume while the domestic side unifies the national energy grid and continues the development of the renewable energy sector. Therefore, it should be in Japan's best interests to initially prioritize the development of their international supply chains to meet their output targets. Despite the benefits gained through supporting domestic projects, they cannot provide an adequate output of hydrogen as their scale is much lower than that of an international supply chain. Securing the output targets for hydrogen in the short term is necessary in creating progress in Japan's decarbonization goals. However, over time, as Japan secure enough imported volume, they can shift their financial allocation towards supporting more domestic projects to expedite their development and support the growth of local energy producers. This supply chain strategy will maximize Japan's output in the short term while focusing on their energy security in the long term.

5.2 – Changes to the Japanese Energy Certificate Market

The integration of hydrogen in Japan through the advancements of the collective national hydrogen supply chain system would lead to certain changes being made to the Japanese energy market as the stakeholders must shift to become more accommodating of hydrogen energy to ensure its continued presence in the energy market.

In terms of changes in the Japanese energy market, the introduction of hydrogen should theoretically accelerate the changes instigated by the phase-in of renewable energy since the two are complementary. As explained in the literature review, one of the most recent changes of significance to energy market policies was the change of the FIT system to an FIP system to better support renewable energy producers. This framework allows renewable energy producers to sell their output at a set premium in the spot market which is then recuperated by energy retailers in the form of consumer surcharges. The FIP system is expected to fade with the continued reduction of renewable energy generation costs which make them directly competitive with fossil fuels in the energy market, eliminating the need to support renewable energy sources with market premiums and certificates. Then, specifically for hydrogen, the green energy certificates market that operates under the JEPX was split in 2021 to provide a platform for hydrogen energy by creating a market for non-fossil fuel energy certificates that didn't fall under the FIP scheme. However, amidst the constant changes made to the system, the certificate model has become overcomplicated which has caused troubles for retailers and consumers in the energy market alike.

In his study of the renewable energy certificate system in Japan, Ishida of the Renewable Energy Institute (2022) pointed out that unlike other developed countries, Japan relies on a system of multiple energy certificates to cover all forms of renewable energy: non-fossil fuel certificates (NFCs), green energy certificates (GECs) and J-Credits. Each certificate has its own requirements and formats for issuance, method of purchase, and conditions for usage. Additionally, these certificates lack attribute information, meaning it is difficult for consumers and retailers to gauge the environmental impacts of the certificates they buy. Unfortunately, hydrogen energy falls under all these certificate formats, making its trading on the JEPX certificate market a complicated process. To address this issue, the certificate system should be simplified to properly represent the premium value of hydrogen in the Japanese energy market. With JEPX's green energy certificate market being split for the purpose of accommodating non-fossil fuel energy sources that are both included and excluded from the FIP scheme, hydrogen energy has a clearly designated market space where it can thrive separately from other renewable energy sources. The certificate model should be reconfigured to differentiate hydrogen energy from other renewable sources. The three existing certificate models should be streamlined to form a single certificate to cover all forms of renewable energy under FIP while a new certificate model should be created to accommodate for hydrogen energy. These new certificates should include the appropriate standardized attribute information to be able to compare the environmental impacts between different certificates to increase the transparency of certificates to retailers and consumers. This new model would allow hydrogen energy to exist wholly separate from renewable with its own certificate in its own trading market which simplifies its trading process and increases the appeal to participate in that portion of the energy market.

Overall, the certificate system has good potential to elevate the use of hydrogen energy in the Japanese energy market. A marketplace for energy certificates can create a simplified platform to trade energy like hydrogen. With the introduction of a its unique certificate system, hydrogen can distinguish itself from other renewable sources in its own market. Not being a part of the FIP scheme, hydrogen energy does not receive financial backing through recuperated consumer surcharges, but it instead is subsidized through the support of individual supply chain projects that are approved by NEDO and MOE as explored in the section concerning hydrogen supply chains. Once hydrogen energy production becomes optimized and experiences significant cost reductions through R&D, it will become cost-competitive and thrive with its own sub-certificate market system in the Japanese energy market.

5.3 – Accepting FC Technology in Japan

The interview with Kohei Masaki highlighted many reasons why FC technology has struggled to spread throughout Japan. With the government's strong focus on FCVs seen in its emphasis in their Basic Hydrogen Strategy and their large allocation of funds toward supporting FCV projects (as seen in Chart 1), they are seen as a key component in their plans. Despite the targets set by the Japanese industry for FCV propagation by 2030 and 2050, the current rate of sales (5,170 units sold by 2020) indicate that they won't be reached. There are a multitude of issues based in many different factors, ranging from production limitations, lacking infrastructure, stiff demand, and institutional barriers.

5.3.1 – Supply-Side Concerns

The most glaring issue on the supply-side of FCV distribution, as highlighted by Masaki, is the high production costs. It can be mainly attributed to the recency of FCV technology which means that advancements can be made to optimize the manufacturing process and lower costs. This mostly concerns the individual components of FCVs such as the fuel-cell stacks. While it can be assumed that continued investment in the R&D of FCVs can lower costs, a critical issue is ignored in this situation. Although Masaki claims that Toyota is working towards achieving economies of scale through scaling up the production volume, the current high production costs prevent that happening. As a result, mass production cannot occur and therefore the manufacturing process will remain inefficient and costly. The complexity of the manufacturing process also hampers this since the assembly of fuel stack units require manual attention and the careful handling of precious metals such as platinum. In 2018, Strategic Analysis Inc. (Willems, 2018) reported that the

Toyota City assembly plant, one of the main manufacturing plants of Toyota, produced a maximum of 6.5 cars per day, highlighting the sluggish production process. Compounded by the lack of a proper supply chain for many of the specific components for FCVs in Japan, the manufacturing process can easily be delayed and interrupted by a volatile stock of materials. These various inefficiencies of the manufacturing process have seriously jeopardized the rate of production; and although the investments in production optimization made by businesses like Toyota and supported by the Japanese government will address some of them, these efforts will take time, money, and coordination to properly accomplish.

Another supply-side issue highlighted by Masaki rests in the lack of infrastructure for hydrogen in Japan. In Toyota's case, as mentioned, the lack of infrastructure for the assembly of FCV units is most harmful to them, but the country is lacking in a stable supply chain system to support the propagation of hydrogen and FC technology. This also ties into the institutional barriers mentioned by Masaki, those being the lack of a regulatory framework and industry norms that allow for the smooth operation of hydrogen supply chains. These issues can once again be attributed to the recency of hydrogen in Japan and therefore requires time to effectively establish. A direct solution to this issue is the achievement of mass-production of hydrogen which creates large and consistent volumes in Japan. By ensuring the mass production of hydrogen (according to the output targets in Table 1), cost reductions can be achieved (according to the cost targets of hydrogen in Table 1). This solution has been explored in the section discussing domestic and international hydrogen supply chains. The main objective here is for hydrogen to achieve cost parity with not only natural gas but also with running costs for EVs. Parallel to this, the Japanese government invested significant amounts of their yearly hydrogen budget (18.6%) to roll out hydrogen refuelling stations, targeting 900 stations by 2030. Trencher et al. (2020) concluded that this funding supports up to 50% of construction costs while many local prefectures cover most of the remaining expenses and operating costs. This support is necessary since the average construction cost of a new hydrogen refuelling station can reach 450 million JPY. Additionally, Masaki mentions the collaboration between various stakeholders such as automakers, governments, and energy companies under the direction of the HPC. The networking facilitated by the

HPC allows companies like Toyota to share costs with other businesses and optimize their operations. While there appears to be significant support for the FCV project in Japan, there are also major areas of concern. It must be noted that with the Japanese government planning to circulate 300,000 tons of hydrogen per year while deploying 800,000 FCVs, the targets are mismatched since this amount would be enough to fuel 3.7 million FCVs. The imbalance becomes more noticeable when considering the target of rolling out 900 hydrogen refuelling stations. Even with strategic placement through data-driven computations and a smart modular station design as stated by Masaki, the number of refuelling stations is dwarfed by the 31,500 gasoline fuelling stations (Trencher, 2020). Simply put, despite the significant investment into FCVs, the infrastructure of the transport sector (including FCVs and their refuelling stations) will not effectively utilize the projected volume of circulated hydrogen in Japan by 2030. This means that additional demand for hydrogen must be created outside of the transport industry, which means that Japan must expand the hydrogen infrastructure to encompass other industries to accommodate for this excess hydrogen. This solution will be discussed later in the Discussion section.

5.3.2 – Demand-Side Concerns

With the demand-side issues, Masaki again attributes the recency of FC technology to the lack of demand expressed by the Japanese public. He explains that the unfamiliarity of the technology due to a lack of education creates major psychological barriers that inhibit consumers from readily embracing products of FC technology. This phenomenon is quite alarming considering the priority that Japan has placed on the market entry of FCVs in the passenger vehicle industry. This is evident in the disproportional targets for the rollouts of the three FCV types identified for production, with 800,000 passenger FCVs planned to be in operation by 2030 while industrial vehicles like FC buses and FC forklifts have targets of 1,200 and 10,000 units by 2030 respectively. Several vehicle manufacturers and local government agencies argue that while production for buses and forklifts will most likely remain limited, it is worthwhile to focus on the mass-production of passenger FCVs to achieve economies of scale and lower production costs of key components such as fuel cell stacks which could then be integrated into other FC vehicles (Trencher, 2020). This focus on the passenger vehicle market becomes problematic even beyond the psychological barriers to accepting FC technology, but the obstacles of competing with both EVs and common gasoline vehicles are quite high. Despite the long-term financial benefits of FCVs highlighted by Masaki, the overall cost of FCV ownership still roughly totals up to 7 million JPY while a typical hybrid vehicle will cost 4 million JPY with common gasoline vehicles costing even less (CMS, 2021). The gulf in gasoline and hydrogen refuelling stations also lowers the appeal of owning an FCV. These issues compound to create a less than desirable position for FCV propagation in Japan. To address this, the Japanese government attempts to subsidize consumer purchases of FCVs, subsidizing 2.38 million JPY for each purchase of Honda's Clarity Fuel Cell model and 1.453 million JPY for each purchase of Toyota's Mirai FCV model (CEV, n.d.). However, even with these financial incentives, the high overall costs of FCVs mean that FCVs will most likely only find success in market penetration with eco-friendly early adopters who highly value the environmental impact of products.

5.3.3 – Alternatives for FC Propagation

Considering the obstacles that FCVs face in diffusing across Japan, alternatives for the acceptance of FC technology should be considered. Despite the large investments made in this venture so far, it has shown little success as seen with the lack of current sales of FCV units and doesn't promise to achieve the targets for output set for 2030 and 2050. Japan's decision to overwhelmingly support FCVs demonstrates a disorder in priorities for hydrogen propagation. The fundamental goal of hydrogen integration as seen in Japan's Basic Hydrogen Strategy as to help decarbonize the energy market. Even with the environmental advantages coupled with some functional advantages highlighted by Masaki such as longer driving ranges and lifespans, the passenger transport sector is already heavily electrified with many hybrid/electric alternatives that serve similar environmental benefits at much lower costs. This makes the market penetration of FC technology much more difficult and therefore requires much greater support to achieve any measure of success. Therefore, an appropriate strategy would be to target industries that lack electrification and could maximize the potential of FC technology to acquire access to affordable and sustainable energy. Remaining in the transport sector, a solution would be to focus on industrial, long-distance vehicles that would utilize the unique features of FCVs effectively. Especially corporate vehicles such as trucks and buses would capitalize on the long driving ranges and lifespans of FCVs that reduce maintenance and fuel costs. Additionally, the rollout of hydrogen refuelling stations would align with this strategy much better than with passenger vehicles, since long-distance vehicles would require fewer and less closely spaced refuelling stations, meaning less stations are necessary to be constructed and they can be in more rural areas along highways that benefit long-distance vehicles rather than in urban areas that suit passenger vehicles. As seen in Table 2, there already exists great potential for the use of hydrogen in the industrial transport sector with FCVs predicted to take up 25% of the freight sector and an 8.5x growth in the entire FCV sector between 2008-2050. By reallocating the hydrogen budget away from the passenger sector and towards supporting the development of industrial FCVs, businesses like Toyota can continue their FCV projects in a different avenue while still being subsidized by the government. An overall transition of focus from the public sector to the industrial sector will greatly benefit Japan's attempts to diffuse FC technology, with even more applicable potential in other sectors such as the steelmaking and chemical industries (Nakano, 2021).

5.4 – Aligning with 3E+S

Ultimately, the integration of hydrogen in Japan through the establishment of a stable supply chain system, the distinguishment of hydrogen in the energy certificate market, and the propagation of FC technology must all adhere to appropriate criteria according to the 3E+S to ensure that Japan strives for energy security, economic efficiency, and environmental protection without compromising safety. Japan's original targets for 2030 when considering the mass integration of hydrogen in the energy market were: 1) for energy security, achieve an energy self-sufficiency rate of 30%, 2) for economic efficiency, reduce energy generation costs in anticipation of rising surcharges, 3) for environmental consideration, reduce CO2 emissions by 45%, 4) for safety, enhance the safety of nuclear energy (JEPIC, 2022). To make the 3E+S targets specific to the issue of the thesis, this section will devise theoretical targets regarding for hydrogen integration using this concept.

For energy security, the primary concern relates to Japan's self-sufficiency which has been discussed during the exploration of Japan's potential hydrogen supply chain system. This issue rests on the balance between Japan pursuing the large output available through the import of hydrogen from international sources and Japan focusing on domestic supply projects to increase the local production of hydrogen. It has been established that despite the benefits of supporting domestic projects, it is necessary to focus on achieving the output targets to create visible progress in the decarbonization of Japan's energy market. By prioritizing the importation of green hydrogen in the short term, Japan has greater chances of meeting their hydrogen output targets which unfortunately means deviating focus from their domestic projects. This indicates that the expectation for self-sufficiency must be lowered to compensate for the increase in focus on international projects. However, with the continued development of the renewable energy sector in Japan and support of various projects by NEDO and MOE, Japan can still expect their self-sufficiency to increase by 2030. A more realistic target would be 20% self-sufficiency instead of 30% when considering Japan's hydrogen integration strategies.

For economic efficiency, the primary concern relates to Japan's ability to reduce hydrogen production costs both domestically and internationally. This factor will decide the economic viability of their hydrogen supply chain system. As explored previously, with the recommendation of initially supporting the development of international supply chains over domestic projects, Japan's focus should be on minimizing the operation costs of their international supply chains. As seen in Chart 3, the production costs of various renewable energy sources around the world already achieve relatively low production costs while all the supply chain costs including liquefaction, pipeline delivery, and international transportation elevate it beyond the targeted cost levels. Therefore, in international supply chain arrangements, Japan should prioritize investments into optimizing the delivery process. Concepts such as the underwater pipeline for a potential Japan-China supply chain that can drastically reduce operation costs in the long term serve as an example.

For environmental consideration, the primary concern relates to Japan’s ability to complement the integration of hydrogen in the energy market with the development of the renewable energy sector. As discussed previously, the two are intrinsically linked because hydrogen energy is most effectively used by storing the excess energy produced by intermittent renewable energy sources such as solar and wind power. Focusing on these two developments is critical towards increasing the share of non-fossil fuel energy generation in Japan and lowering carbon emissions. The simulation results of Table 2 suggest that 59% of the national energy supply can be generated through renewable energy with 13% coming from hydrogen. This would represent a 41% share increase in renewable energy from Japan’s 2019 energy generation mix and a corresponding decrease in fossil fuel use (JEPIC, 2022). Accordingly, Japan should target a 41% decrease in carbon emissions by 2030.

For safety, the primary concern relates the formation of a stable and reliable regulatory framework for the handling of hydrogen in Japan. Despite the difficulties expressed by Masaki of handling a local hydrogen supply chain under the High-Pressure Gas Safety Act that treats hydrogen the same as other more dangerous gases, steps must be taken to ensure that the policies for handling it are attentive and don’t endanger other infrastructures or people. Japan should follow regulatory framework designs like those implemented by the Department of Energy in the United States (Ehrhart, 2021) that explicitly highlight the physical and chemical properties of hydrogen in relation to its status during various transportation and storage processes encountered during a hydrogen supply chain system. Formulating a specific framework to handle hydrogen will make the operation of a domestic supply chain system smooth and safe for all stakeholders involved.

Overall, with the consideration of new strategies to integrate hydrogen in the Japanese energy market, adjustments to Japan's targets under the 3E+S concept can be devised to carefully guide the country's efforts towards an environmentally considerate and economically viable energy sector.

6 – CONCLUSION

In the following section, the main findings of this thesis are summarized, while implications for the business field, study limitations, and further suggestions are outlined.

6.1 – Main Findings

The objectives of the research were to investigate the properties of hydrogen energy as a component in energy markets and identify a comprehensive strategy to integrate it across Japan's energy market in an environmentally beneficial and economically viable manner. Based on literature review, a conceptual framework was created, which depicts the steps toward formulating this strategy. The conceptual framework was further verified and expanded upon with the data collected from the research conducted.

Based on the research performed and compared against relevant literature, the following findings are made:

1. Japan's pursuit of a hydrogen supply chain system is equally important between its international and domestic fronts, but it is necessary to prioritize the development of the former to secure the volume targets set for 2030 before shifting attention to domestic supply chain projects to support local energy companies and increase Japan's self-sufficiency.
2. Japan's arrangements for international hydrogen supply chains should prioritize the importation of green hydrogen rather than cost-competitive blue

hydrogen to avoid the difficulties of managing the difficulties of CCS associated with blue hydrogen.

3. To create an accommodating environment for hydrogen in Japan's energy market, hydrogen should be provided its own energy certificate model in its own market space within JEPX to distinguish itself from other renewable energy sources. Additionally, without the support of an FIP scheme backed by Japan's government, local ministries should continue to back domestic supply chain projects to lower production costs and therefore selling prices to attain cost competition.
4. Japan should redirect their focus of spreading FC technology across the country from supporting passenger FCV projects toward industrial hydrogen that maximize the potential of the energy density and reliability of hydrogen FC units.

6.2 – Implications for International Business

The findings of this thesis have several implications for the field of international business. Although this study focused on the energy market situation in Japan, it is easily applicable to energy markets of other nations interested in developing their own hydrogen infrastructure and supply chain system. As a renowned leader of hydrogen and FC technology, Japan is a pioneer in this sector and serves as an example for other nations to follow in terms of hydrogen integration.

As established in the literature review, hydrogen is a capable energy carrier that has the potential of addressing a variety of environmental and economic concerns across an energy market. The findings and discussion outline a variety of international and domestic policies that can be assumed to encourage the integration and use of hydrogen in an energy market. They also suggest ways to streamline energy markets to make them more accommodating for renewable energy sources and incentivize the participation of energy retailers and consumers.

Although the policies and targets mentioned throughout the thesis are specific to Japan, they can be used as guidance for other nations that wish to pursue a similar scale of hydrogen integration.

6.3 – Limitations

It is important to note that this study faced a multitude of limitations due to the lack of relevant, empirical data relating to the integration of hydrogen in the Japanese energy market. This can mostly be attributed to the recency of hydrogen in the field and therefore a lack of useful studies and research papers that could be used for my secondary research. Additionally, specific information about supply chain systems such as cost breakdowns were hard to uncover as the information is not public and guarded by government agencies.

Additionally, for the qualitative research conducted, only one semi-structured interview was performed which provides limited perspective on the interview topic. However, only one interview was conducted due to their relevant professional position and accessibility which was hard to identify in other interview candidates. Moreover, the information retrieved from the interview was mostly backed by other academic literature.

6.4 – Suggestions for Further Research

Several areas of further research have been hinted at throughout the thesis. Firstly, a more thorough and logistical study of international hydrogen supply chains could be conducted to test the feasibility of potential arrangements to import green hydrogen from other countries. Secondly, this thesis only investigated the use of hydrogen in the passenger and long-distance transport sector. A study into the other potential industrial applications of hydrogen across other sectors in Japan could prove useful in exploring potential relationships between the energy sector and other industries. Thirdly, as brought up during the exploration of domestic hydrogen supply chains, a study into the formation of a proper regulatory framework to control the production, transport, and storage of hydrogen in Japan could be useful in establishing industry standards for the management of hydrogen. Such a study was not conducted here due to the lack of data and information on the topic.

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APPENDICES

Appendix A: Interview Questions

Supply-side concerns of FCVs

1. High production costs are known to be a concern behind the distribution of Toyota's FCV units. Consequently, how can FCVs compete with popular electric car models that address carbon emission issues in similar ways?
2. What efforts are Toyota putting towards lowering FCV production costs?

Infrastructure concerns of FCVs

3. How is Toyota cooperating with the electric providers and retailers of Japan to develop a stable and low-cost hydrogen supply system?
4. How is Toyota optimizing the rollout of hydrogen refuelling stations for FCVs in terms of costs and location while decreasing investment risks?

Demand-side concerns of FCVs

5. How has Toyota segmented and targeted the Japanese market to achieve maximum market penetration and demand for FCV units?
6. How has Toyota addressed potential psychological barriers that inhibit demand for FCV units such as higher upfront costs, refuelling inconveniences, reliability concerns, and narrow product lines?
7. How has Toyota attempted to increase public awareness regarding the benefits of FCV units to boost their societal acceptance and familiarity?

Institutional concerns of FCVs

8. Have any institutional barriers restricted Toyota's capacity to operate their hydrogen supply and product system? If so, how has Toyota attempted to address them?

Appendix B: Interview Transcript

Interviewer: Joni Mäkinen

Interviewee: Kohei Masaki

Location: Zoom

Date & Time: 4/3/2023, 16:04 (GMT+9)

1. This is a debate that has started to become more important to discuss with hydrogen fuel cells becoming more prominent across many industries. And while FCVs are constrained by their higher manufacturing costs when compared to EVs, this cost difference is anticipated to narrow as fuel cell technology develops and economies of scale are attained. But even with this limitation, there are many reasons why FCVs can still be competitive with EVs. The overall cost of ownership—which includes operating and maintenance expenses over the course of a vehicle's lifetime in addition to the initial purchase—must be considered. In this respect, FCVs have several benefits, including a longer driving range than the majority of EVs, which means fewer stops for refuelling. In business and industrial settings, where time is money and downtime can be expensive, this is crucial. In addition, FCVs last longer than EVs. Fuel cells have a longer lifespan and require less upkeep than EV batteries, which deteriorate over time and need to be changed. This indicates that over the course of their lifespan, FCVs require less general maintenance. When searching for a new car, many of these factors are crucial for our customers. Additionally, FCVs have a higher energy density than EV batteries, allowing them to store more energy in each amount of area for larger vehicles in the transportation sector. Due to the need for more engine power than a normal car, this makes FCVs better suited for larger vehicles like trucks and buses. So overall, our FCVs can compete with EVs despite the higher production costs.

2. As you might imagine, this is one of the priorities within the FCV department of Toyota, so our department has several strategies to address this issue.

Scaling up production volume is one of the major strategies we use to reduce production costs. We can achieve economies of scale as production volume rises, which can greatly lower the cost of manufacturing procedures. We already produce the Mirai FCV model in greater quantities than in prior years, and we intend to keep doing so in the future. To lower production costs, we are looking into methods to improve automation, cut waste, and streamline the production process. To increase the effectiveness and efficacy of FCVs, we are also investing in R&D. We can reduce the size and weight of the system while keeping or even enhancing its performance by creating more effective fuel cells and other parts. We are also working with suppliers to reduce the cost of raw materials and components. By collaborating with our suppliers and encouraging competition among them, we can save costs through better pricing and more efficient supply chains. Most of these strategies may seem quite standard, but the recent introduction of hydrogen fuel cell technology means that large advancements can be made that greatly optimize both the supply and demand of FCV units.

3. To create a reliable and affordable hydrogen supply system, Toyota has been collaborating closely with electric companies and merchants in Japan over the past few years. We are aware that the availability of a dependable and cheap hydrogen supply infrastructure is just as important to the success of FCVs as the availability of the vehicles themselves. We are interacting with them in part through the HPC. To promote and create a trustworthy, secure, and economical hydrogen supply chain, the HPC brings together a wide range of stakeholders. To plan the building and management of hydrogen stations as well as to create technologies and standards for hydrogen production, storage, and transportation, the HPC collaborates closely with electric companies and retailers. Toyota is also collaborating with retailers and electric service providers to create new financing and business models that can help to reduce the price of hydrogen distribution and manufacturing. For instance, we are looking into creative ways to optimize the electrolysis procedure and reduce the price of producing hydrogen. As part of our efforts to increase general knowledge and understanding of hydrogen as a fuel, we are also working with retailers and electric companies. We think we can contribute to

the development of a hydrogen supply infrastructure by informing the people about the advantages of hydrogen and encouraging its use as an energy source.

4. The optimization of this process has a lot of moving parts involved so it must be planned carefully. But the primary component of our strategy is to put efficiency and adaptability first to make sure that Toyota continues to produce a model that is advanced and adaptive. Working together with other stakeholders is a crucial component of this because Toyota recognizes that developing a hydrogen refuelling infrastructure is a lengthy and expensive expenditure. As a result, we are working with other stakeholders, including local governments and energy providers, to split the expense of setting up and maintaining refuelling stations. Toyota is also employing a data-driven location planning strategy to determine the most advantageous places for hydrogen refuelling stations. To determine the most effective location planning methods, we examine variables like population density, vehicle traffic, and proximity to already-existing hydrogen infrastructure. We can make sure that refuelling stations are used effectively and efficiently by strategically placing them in busy locations. Toyota is using a modular station design that can be readily expanded or relocated as the demand for hydrogen fuel rises so that Toyota can cut costs. This strategy enables us to construct stations gradually, lowering initial costs while ensuring that we can expand rapidly as demand rises. Toyota's close contact with the Japanese government to secure financial and legal support for the rollout of hydrogen refuelling stations also contributes to cost savings. Incentives and funding have been given by the Japanese government to encourage the development of hydrogen infrastructure, which has helped to lower costs and lower investment risks. This system is designed to allow Toyota to continuously refine our strategies to optimize costs, reduce investment risks, and ensure that we are meeting the needs of our customers.

5. Toyota originally targeted early adopters who are interested in the newest automotive technologies and are willing to pay a premium for them. This is

because hydrogen fuel cell technology is still relatively new in the transportation industry. These early adopters were frequently eco-aware shoppers who value green and sustainable products and who thus make up a significant portion of the FCV customer group. Toyota also focused on the business fleets market segment. Toyota wanted to raise the company awareness and use of fuel cell vehicles by making them available to businesses. Additionally, it is simpler to plan for our deployment of hydrogen refuelling stations because business fleets have a predictable daily mileage and refuelling routine. To expand the use of FCVs in Japan, Toyota has also targeted government fleets, such as municipal and public transportation fleets. Toyota has also focused on geographical regions, particularly Japanese cities with dense populations and lots of traffic. In addition to having a higher demand for fuel-efficient cars, these regions are also more likely to already have hydrogen infrastructure in place or have the potential to do so. Toyota has launched advertising campaigns that emphasize the advantages of FCVs, such as their environmental friendliness, quiet operation, and performance, to support this market penetration. To improve the appeal of FCVs, we are also looking into novel business models that can help consumers lower the overall cost of ownership. For example, we are exploring ways to lease the fuel cell stack to customers, rather than selling it outright. This can help to lower the initial purchase cost of the vehicle and make it more affordable for consumers.

6. Many of these potential psychological barriers are addressed through Toyota's production and marketing strategy. As mentioned, with high costs being a topic of major concern, Toyota attempts to address this by offering leasing options for FCV units. This allows customers to pay a lower monthly fee rather than the full cost of the vehicle upfront. Toyota also emphasizes the long-term financial benefits of FCVs, such as reduced fuel expenses and tax benefits. Inconvenient refuelling is another problem we've found. Toyota has so far concentrated on establishing a network of hydrogen refuelling stations in strategic areas. Customers can now refuel their FCVs quickly and simply without having to take a long detour or wait a long time. Toyota then stresses the significant R&D investments made in collaboration with the Japanese

government to create high-quality and dependable FCV units to address reliability concerns. Toyota has also provided maintenance plans and extended warranties to reassure customers about the dependability of their cars. The problem of limited product lines is another issue that we work to address. Toyota has responded to this by releasing a variety of FCV models that cater to various customer kinds. To meet the various requirements of our clients, this includes passenger cars, SUVs, and commercial vehicles, all of which have unique features. While these product lines need time to develop to meet the variety seen in electric and gas car models, Toyota is on track to do so.

7. This ties back to my answer about overcoming psychological barriers. One of the most important things to consider when strategizing the distribution of a technology like this is the education and knowledge of customers. As said, hydrogen fuel cell technology is quite new, so many consumers may be unaware of its properties. To effectively educate consumers and increase their familiarity with FCV products, Toyota has implemented promotional campaigns and educational materials that emphasize the environmental friendliness of FCVs as well as their advantages in terms of performance and quiet operation. To educate the public about the technology underlying FCVs and their potential to resolve environmental issues, these promotional efforts pair well with the complementary educational materials, like brochures and videos. These resources are accessible online, at car shops, and at exhibitions featuring FCVs. To offer people the chance to experience FCVs first-hand, Toyota has also planned test drive events in Japan. People can test FCVs at these events and learn more about their capabilities and environmental advantages. The ability of test drives to increase awareness among prospective customers who might be reluctant to adopt new technologies has been demonstrated to be successful, which is very helpful for us. To raise knowledge and support for FCVs, Toyota has also partnered with other institutions, such as regional authorities, academic institutions, and environmental groups. Through these alliances, Toyota has been able to reach a larger population and spread awareness of the advantages of FCVs

among various societal groups. To raise public knowledge and promote societal acceptance of FCVs, Toyota has also made significant media coverage investments in Japan. Press statements, interviews, and features in print, digital, and other media are all included in this.

8. One institutional barrier we've faced is the lack of proper infrastructure for hydrogen supply and distribution in Japan, but I've addressed that concern in a previous question, so I won't go over it here. The complicated regulatory framework for hydrogen production, storage, and transportation in Japan, however, is another urgent problem. Toyota has found it challenging to create new infrastructure for hydrogen refuelling sites as a result, and the rollout of this infrastructure has been delayed. Toyota has attempted to develop a regulatory framework that encourages the growth of hydrogen infrastructure to address this issue, working with governmental organizations and business associations. In addition to pushing for industry norms for hydrogen fuelling, we have been advocating for changes to laws governing hydrogen production, storage, and transportation. In the upcoming years, significant changes are anticipated to promote the development of FCVs in Japan. Toyota still turns to public funding and partnerships with other businesses to share the costs of infrastructure development, even though Toyota has worked closely with the Japanese government to secure funding for hydrogen infrastructure development and R&D. While there are issues, Toyota has been successful in promoting the use of FCVs in Japan and building a network of hydrogen refuelling sites.